CCUS & OFFSHORE WIND OVERLAP STUDY REPORT

REPORT FINDINGS AND RECOMMENDATIONS

Offshore Renewable Energy Catapult

Net Zero Technology Centre
Technology Driving Transition

Project Sponsor:
The Crown Estate

CCUS & OFFSHORE WIND OVERLAP STUDY REPORT

Study Findings and Recommendations

REPORT

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Project Sponsor

In Partnership with

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Foreword

There have been few moments in history where the need to collaborate has been so great. The target to achieve net zero emissions by 2050 has galvanized nations, governments, industries and individuals, around a common, and urgent, goal.

The seabed has a critical role to play in offering up solutions to this seismic decarbonisation challenge; not least as a site for the fast-growing offshore wind industry, and a location for the safe geological storage of carbon, through Carbon Capture, Usage and Storage (CCUS).

The vast potential offered by these technologies is exciting, but unlocking this potential at the scale needed isn't straightforward. The marine environment is already a busy place, home to a wealth of ecology and biodiversity, industries such as offshore wind, marine aggregates, cabling, fishing and shipping, coastal communities; and much more. Finding ways to fit more clean energy technology and infrastructure into this environment, without unintended consequences, inevitably involves collaboration and co-ordination on a scale we have not seen before.

Big as the challenge is, the good news is that there is a strong appetite across government, industry, environmental organisations and many more, to work in concert to piece together this giant jigsaw puzzle. This can already be seen in collaborative programmes such as The Crown Estate's Offshore Wind Evidence and Change programme and the BEIS Offshore Transmission Network Review.

This report, commissioned by The Crown Estate in association with Crown Estate Scotland and the Oil & Gas Authority, is another example of this collaboration; working together to develop a detailed understanding of how vital Offshore Wind and CCUS technologies can grow and co-exist, so that their contribution to net zero can be maximised.

The ORE Catapult and the Net Zero Technology Centre have worked together to provide a clear analysis and practical recommendations on the ways in which offshore wind and CCUS projects can co-exist and we are committed to collaborating with industry, policymakers and stakeholders to drive forward the report recommendations. At the centre of this response is the formation of the Offshore Wind and CCUS Co-location Forum, a ground-breaking collaboration which will advise on how the UK can maximise the potential of the seabed for these two critical activities.

As we work towards making a net zero future a reality, this report is another valuable piece in the jigsaw. We hope you find it a useful resource to aid improved understanding and decision-making in this vital area.

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Nomenclature

3D	Three dimensional
CCS	Carbon capture and storage
CCU	Carbon capture and utilisation
CCUS	Carbon capture, utilisation and storage
CO_2	Carbon dioxide
LiDAR	Light Detection and Ranging
MMV	Monitoring, measurement and verification
OGA	Oil & Gas Authority
ORE Catapult	Offshore Renewable Energy Catapult
OSPAR	Oslo/Paris convention (for the Protection of the Marine Environment of the North-East Atlantic)
TLP	Tension Leg Platform
TRA	Technical risk assessment
TRL	Technology readiness level
UK	United Kingdom

1 Executive Summary

The Carbon Capture, Utilisation and Storage (CCUS) and Offshore Wind industries are key to meeting the UK's legally binding Paris Agreement commitment to reduce greenhouse gas emissions to net zero by 2050 and enable decarbonisation of the economy.

Offshore Renewable Energy Catapult (ORE Catapult) in partnership with the Net Zero Technology Centre has carried out a comprehensive and unbiased study to examine the additional risks that may result from overlapping of Offshore Wind and CCUS projects and how these risks may be managed.

Ideally, the siting of Offshore Wind and CCUS projects should be planned to avoid overlap where possible. However, as the UK looks to expand Offshore Wind and CCUS opportunities to meet net zero targets, it is anticipated that there will be a number of areas that will require infrastructure in the same location. The information contained within this document is focused on where overlapping Offshore Wind and CCUS facilities introduces new risks that aren't inherent in the execution of standalone projects and on areas where overlapping Offshore Wind with CCUS projects results in a marked increase in the potential or impact of inherent risks.

The study consulted a range of organisations and utilised a technical risk assessment process to identify and quantify the potential risks and mitigations associated with developing overlapping CCUS and Offshore Wind projects. The study sought to identify potential risks and opportunities for co-location of generic CCUS and Offshore Wind projects and therefore did not consider issues associated with any specific projects.

The study has concluded that with current technologies and practices the co-location of CCUS and Offshore Wind projects present a number of challenges that will need to be overcome to allow the two industries to deploy their respective technologies optimally over the same area of seabed. In order to be feasible, the respective industries will need to deal with the main drivers of possible spatial incompatibility identified in this report, focusing on:

The study identified a total of 46 risks associated with developing overlapping projects; 16 of which were classified as having a high impact, 26 having a medium impact and 4 having a low impact. In addition 12 potential opportunities were recognised when project were effectively co-located. These risks and opportunities have been categorised into common elements.

The following list of common elements captures the majority (all but 2 of the medium impact risks) of the identified risks across all project lifecycles. As a result, these can be considered to be (in no particular order) the common elements for potential risk for overlapping Offshore Wind and CCUS projects as summarised in Figure 1.1.

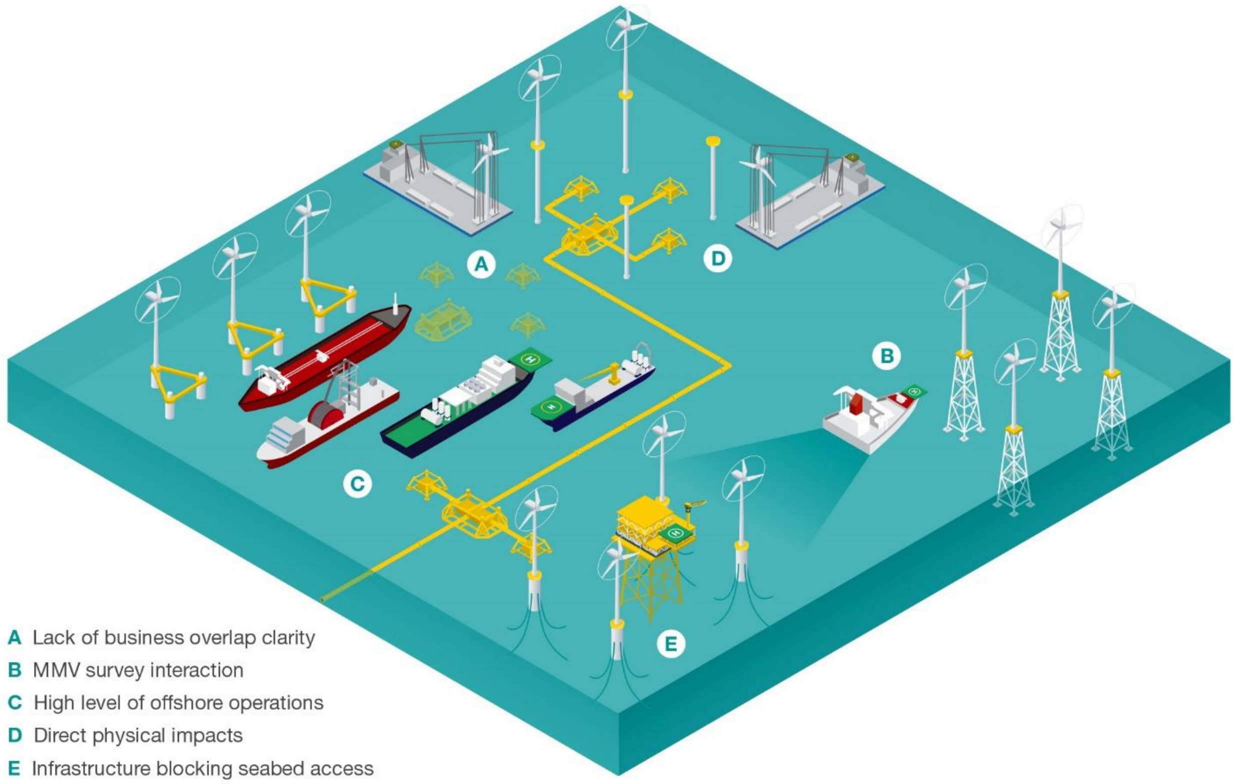

Figure 1.1: Common Elements of Risks for Overlapping Offshore Wind and CCUS Projects

A. A lack of clarity over how issues associated with overlapping Offshore Wind and CCUS projects such as development planning / precedence, promotion of collaboration, alignment of standards, cross-industry liabilities and dispute mediation would be handled.

B. The requirement to perform monitoring, measurement and verification (MMV) surveys (particularly seismic surveys) for CCUS projects across their lifecycle and the interaction with Offshore Wind infrastructure.

C. A higher level of offshore operations that result from locating two projects in the same area.

D. Direct physical impacts to infrastructure or personnel due to incidents occurring as a result of overlapping projects.

E. The physical infrastructure of a pre-existing project blocking access to the seabed or modifying the requirements for new projects.

A range of mitigation measures for reducing the impact of the identified risks were assessed, which were classified into the following categories:

- Good practice mitigation measures: Mitigation measures that can be applied immediately without further study or development based upon good practice across the Offshore Wind and CCUS industries.

- Future mitigation measures: Mitigation measures that could potentially be applied in future but require some further technology development or research to determine whether they are feasible and economic.

The overall impacts of the identified risks across the individual lifecycles of overlapping Offshore Wind and CCUS projects and the residual risk levels following implementation of the identified mitigation measures are illustrated in Figure 1.2 (red = high concentration of risks and impacts, amber = medium concentration of risks and impacts, green = low concentration of risks and impacts).

Figure 1.2: Offshore Wind and CCUS Project Lifecycle Risk Levels

The identified current good practice measures are dependent on good co-ordination and communication between overlapping project developers and across both industries in a wider sense plus applying lessons learned from the upstream oil and gas industry to mitigate against any detrimental impact of overlapping project site activities. These measures mainly impact common elements C to E, which are primarily associated with ensuring that overlapping projects consider each other's needs and activities.

The following potential future mitigations should be considered across a number of the common elements underlying risks for overlapping Offshore Wind and CCUS projects:

- Consider appointing a common oversight body for overlapping Offshore Wind and CCUS projects, consisting of a combination of government and industry bodies, to provide input to enable issues such as overlap planning opportunities, development planning / precedence, promotion of collaboration, alignment of standards, cross-industry liabilities and dispute mediation to be handled.
- Pro-actively review where Offshore Wind and CCUS projects could potentially overlap (i.e. where are the good CCUS stores versus the high potential Offshore Wind sites) and ensure a combined approach to planning in those areas.

The application of the above future mitigations has the potential to further reduce the overall impact across the majority of the identified risks.

Even assuming that initial CCUS site investigation can be carried out before the start of development operations of a co-located Offshore Wind site, a critical risk is presented by the interaction of seismic surveys required for CCUS MMV operations with Offshore Wind infrastructure. The key recommendations for areas of future work to resolve this major risk area include:

- Pro-actively review where Offshore Wind and CCUS projects could potentially overlap and consider performing site characterisation activities in these areas prior to any Offshore Wind or CCUS project development.
- Clearly define the best practice and minimum acceptable practice in terms of CCUS MMV schemes, through the regulator performing a review of current MMV requirements to minimise the need for seismic surveys in particular, and ensure that these are taken into account when planning overlapping CCUS and Offshore Wind projects on a case-by-case basis.
- Provide government/regulator support for a future technology development campaign in reservoir characterisation and MMV to remove the dependency on new seismic acquisition (e.g. forward modelling of response of different reservoir types' rock physics response to CO_2 flood; what constitutes appropriate monitoring post-injection).

While differing types of Offshore Wind (e.g. fixed versus floating wind turbine sub-structures) and CCUS (saline aquifer store versus depleted hydrocarbon store) and levels of overlap/proximity do incrementally affect the risks identified in this study, they do not change the above overall conclusions for good practice mitigations or recommendations for areas of future development in managing those risks.

There are two specific areas of study where it is recommended that immediate action is taken to further understand the risks associated with Offshore Wind and CCUS projects being developed in close proximity:

- Conduct further study to determine the potential allowable minimum separation distance between a CCUS storage complex and an Offshore Wind site to:

- Minimise degradation of seismic survey results from Offshore Wind ambient noise or foundation signal reflection issues.
- Examine the challenges presented by limiting access for wells and relief wells, including their exclusion zones for vessel and helicopter access.
- Enable safe and efficient rig helicopter operations support (crew change, emergency response, search and rescue) within the wind farm.
- Minimise impact to reduction of conventional weather window for rig mobilisation within wind farms.
- Assess the level of risk of corrosion damage to offshore wind infrastructure caused by saline brine displacement from CO_2 injection into saline aquifers at depth so that any mitigating measures such as separation distances between brine release wells and wind turbine substructures can be quantified and put into practice.

There is significant benefit and value in investing in developing the potential future mitigation measures identified in this study to reduce the overall risk presented by overlapping Offshore Wind and CCUS projects. A concerted, coordinated effort will be required to deliver this with sufficient pace.

Following issue of this report, it is highly recommended that an over-arching committee (e.g. formed from one or more of The Crown Estate, Crown Estate Scotland, the OGA and an Offshore Wind representative body) takes ownership and coordinates the implementation of the areas for further work identified in this study to ensure that the risks and opportunities associated with co-locating Offshore Wind and CCUS projects are fully understood and appropriate mitigation measures are explored in detail ahead of the future development of such projects.

2 Introduction

The Carbon Capture, Utilisation and Storage (CCUS) and Offshore Wind industries are key to meeting the UK's legally binding Paris Agreement commitment to reduce greenhouse gas emissions to net zero by 2050 and enable decarbonisation of the economy.

The UK's world-leading Offshore Wind industry is set to grow significantly in the next decade with the Government's commitment to deliver 40 gigawatts of capacity by 2030 and a potential target of 75 to 150 gigawatts by 2050 [1].

At the same time, the UK is spring-boarding a Carbon Capture, Utilisation and Storage (CCUS) industry capable of transporting and storing between 60 and 180 million tonnes per year of carbon dioxide (CO_2) by 2050 in subsurface formations offshore [2]. This is likely to be achieved by a combination of reusing depleted oil and gas fields, where there is certainty over the storage potential, and by developing storage in new saline aquifers for storage.

As the UK looks to expand Offshore Wind and CCUS opportunities to meet net zero targets it is anticipated that there will be a number of areas that will require infrastructure in the same location. While CCUS storage locations will generally be located between 1,000 and 2,500 metres below the seabed, they will require surface infrastructure to transport, distribute and inject the CO_2 and will require surface activities to measure, monitor and verify the security of CO_2 injection and storage as well as access to wells for drilling activities.

The requirements of any overlap of these two types of infrastructure projects at seabed surface level is therefore a key issue that will affect how projects utilising the same area or parts thereof can develop with the maximum amount of co-location. In the first few CCUS projects coming forward in 2020, a number of critical interfaces and issues have already been identified.

The Crown Estate, working in association with the Crown Estate Scotland and the Oil and Gas Authority have awarded this work to the Offshore Renewable Energy Catapult (ORE Catapult) in partnership with the Net Zero Technology Centre to carry out a comprehensive and unbiased study to examine the additional risks that may result from overlapping of Offshore Wind and CCUS projects and how these risks may be managed.

The information contained within this document is focused on where overlapping Offshore Wind and CCUS facilities introduces new risks that aren't inherent in the execution of standalone projects and on areas where overlapping offshore wind with CCUS projects results in a marked increase in the potential or impact of inherent risks.

This document gives clear guidance on what existing management techniques should be applied to manage risks arising from overlapping Offshore Wind and CCUS projects and recommends areas of further work to improve the management of overlap risks in future.

The primary objectives for this study were to:

- Identify the material issues that could impact either CCUS or Offshore Wind projects where there is an overlap, with a description of how each one is expected to impact the affected party through their project lifecycle.
- Provide a high-level risk assessment of the causes of the impact and what existing, new or future technology or process improvements would mitigate or remove the impact on the affected party and what the implications might be for the originator.
- Prioritise the issues in terms of level of impact, identifying what research and development, supply chain development, evolving standards, ongoing or further study work is required to find solutions acceptable to both parties.
- Determine what the key issues are that need to be considered when developing Offshore Wind or CCUS projects to minimise the potential for overlap issues in future.
- Provide recommendations for further detailed studies and innovation requirements.

3 Scope and Methodology

To ensure a robust assessment of the potential risks and mitigations associated with developing overlapping CCUS and Offshore Wind projects, the study consulted a range of organisations, including:

- The Crown Estate.
- Crown Estate Scotland.
- Oil & Gas Authority (OGA).
- Carbon Capture and Storage Association.
- Representatives from the Offshore Wind industry (Ørsted).
- Representatives from the CCUS industry (BP, ENI and Pale Blue Dot Energy).
- ORE Catapult.
- Net Zero Technology Centre.

The study sought to identify potential risks and opportunities for co-location of CCUS and Offshore Wind projects and did not consider issues associated with any specific projects.

The scope and scale of risks (an opportunities) was identified using a Technical Risk Assessment (TRA) process in line with industry standard BS EN 31010:2019. This process provides a methodology whereby data and information are systematically structured to support decision making where there is a degree of uncertainty. It offers the ability to recognise and capitalise on opportunities more successfully, and enables clear, unbiased articulation of the key factors which contribute risk as well as why they are important.

The three phases involved in the TRA processes are summarised in Figure 3.1.

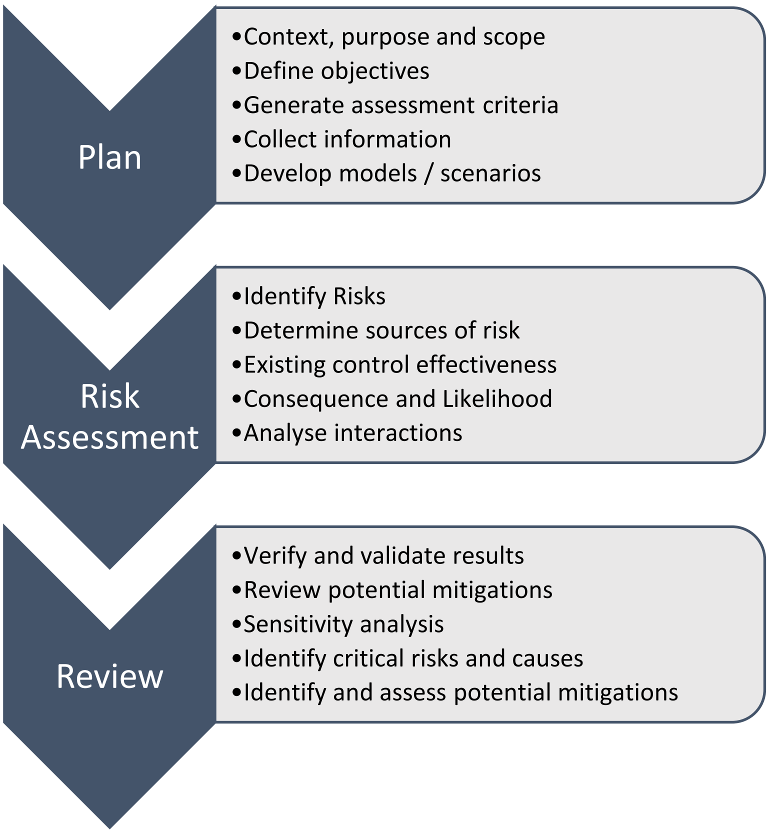

Figure 3.1: Technical Risk Assessment Process

Interactive workshops were held with input from stakeholders to assist in identifying the potential risks associated with overlapping Offshore Wind and CCUS projects plus the potential mitigations that could be applied to manage those risks.

In line with common industry practice, each identified risk and opportunity was assessed to determine its potential consequence and likelihood of occurrence across the following categories:

- Personnel
- Environment
- Asset
- Reputation
- Schedule
- Social
- Financial

The matrices used to assess the potential consequences and likelihood of each identified risk and opportunity are contained within Appendix 1 for reference. These matrices were developed using common industry practice and input from stakeholders to ensure that, although risks were rated subjectively, the assessment was fair and ensured no bias between risks.

The potential mitigations for each identified risk were then considered and their impact on the consequence and likelihood of the associated risk quantified using the same risk assessment matrix. The mitigations identified within the work were categorised as being either “current best practice” or “potential future practice” to provide clear insight into what can be achieved now to assist in managing the risks associated with overlapping Offshore Wind and CCUS projects and where future efforts should be concentrated to improve management of those risks going forward.

The potential for interaction across each stage of a project’s lifecycle for Offshore Wind and CCUS was examined in a pair-wise fashion as illustrated in Table 3.1. This was to ensure that all scenarios and eventualities were systematically explored to develop a full picture of the potential risks and opportunities.

		CCUS				
OFFSHORE WIND		Exploration & Appraisal	Development	Operations & Maintenance	Decommissioning	Post-decommissioning
	Develop					
	Installation & Commissioning					
	Operations & Maintenance					
	Decommissioning					

Table 3.1: Offshore Wind and CCUS Lifecycle Matrix

This allowed the impact of identified risks across different project stages to be clearly understood and provided focus on project lifecycle stages that are particularly susceptible to risks arising from overlapping Offshore Wind and CCUS projects.

4 Project Development Types

4.1 Offshore Wind

4.1.1 Introduction

Since the installation of the first offshore wind farm in the UK in 2000, there has been a rapid growth in the sector that has led to the UK installing approximately 2,300 offshore wind turbines producing approximately 10.4 gigawatts of capacity and becoming the global leader in this sector [3]. The rate of growth for the Offshore Wind industry is set to increase to meet the UK government target of installing 40 gigawatts of offshore wind production by 2030 as part of the UK's plans to transition to net zero emissions by 2050 [4].

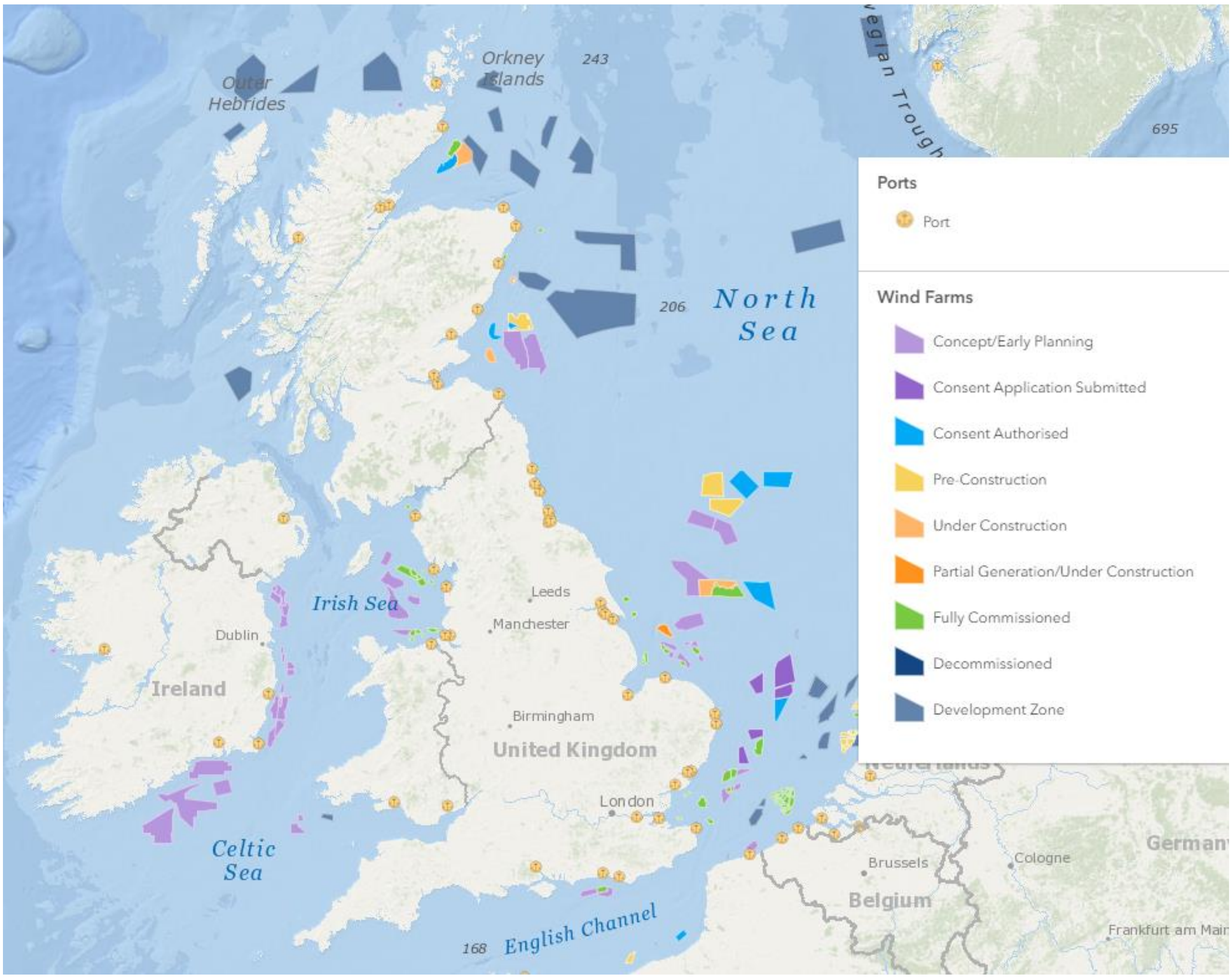

Figure 4.1: Map of UK Installed and Potential Offshore Wind Sites as of 2021 [3]

Figure 4.1 shows the current and planned future Offshore Wind locations in the UK. The area of seabed required for Offshore Wind is expected to increase in the next decade to meet 2030 targets and studies into key future resource areas were published by The Crown Estate [5] and Marine Scotland [6] in 2020. it is likely that there will be some interaction with future CCUS projects.

The “amount” of seabed area required for Offshore Wind projects is related to the number of turbines and the spacing required between the turbines. The spacing between wind turbines is driven by the need to minimise the aerodynamic losses between turbines due to turbulence from wakes while maximising the use of the leased space. Wind farms are installed in a grid formation orientated in the direction of the prevailing wind. If the cost of energy production per unit (turbine) is to be maximised, the distance between turbines can be approximately 10-15 times the diameter of the wind turbine rotors. However, wind farm designs tend to be in the region of 6 to 10 turbine rotor diameters in the direction of the prevailing wind with a lateral spacing width in the order of 4 to 8 turbine rotor diameters [7].

At the time of writing this report, the largest and most powerful wind turbine in the world is the 14-megawatt SG 14-222 DD turbine designed by Siemens Gamesa, which has a rotor diameter of 222 metres [8]. The spacing for a wind farm based on these turbines would be circa 1.3 to 2.2 kilometres into the prevailing wind direction with a lateral spacing of circa 0.9 to 1.8 kilometres.

Of the operational wind farms in the UK, the average number of turbines is 58 per wind farm [3]. This is expected to increase slightly going forward due to larger site areas being developed. Additionally, the increasing size of new turbines being developed means that less turbines are required for the same power output.

4.1.2 Offshore Wind Development Types

Offshore Wind developments tend to be similar in terms of their constituent elements apart from the type of substructure used to install the wind turbine. The type of substructure selected for the wind turbines is driven by the water depth at the wind farm location as well as ground conditions. The following figure provides a general guide as to the “transition depth” where it is generally more economical to use a fixed substructure (e.g. a monopile or jacket structure) versus a floating substructure (e.g. tension leg platform, spar or semi-submersible):

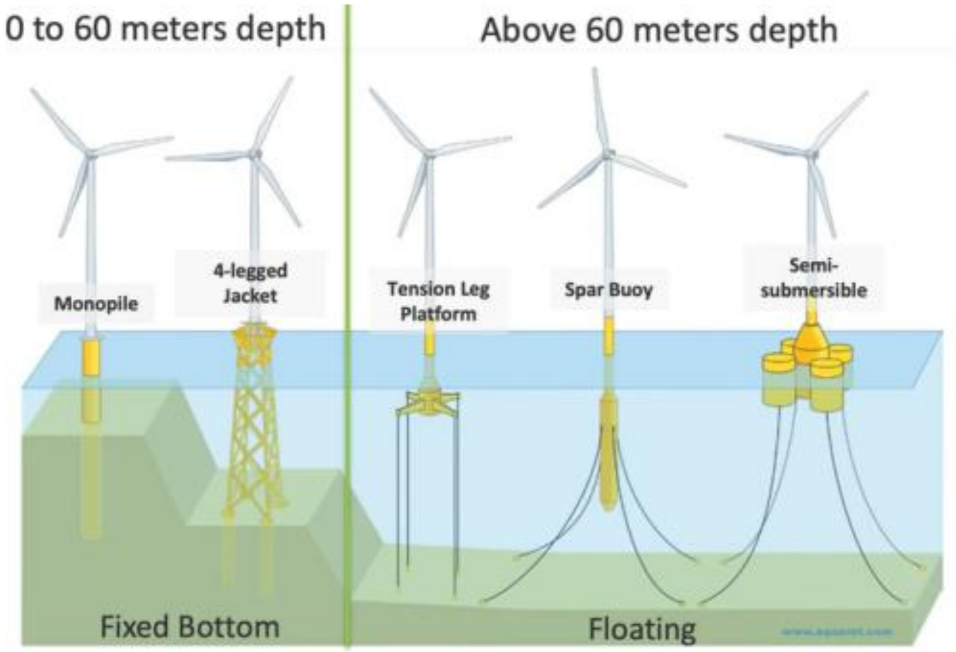

Figure 4.2:Fixed versus Floating Offshore Wind Substructures [9]

The foundations for fixed monopile substructure vary depending on the size of turbine and water depth but tend to be in the order of 5 to 10 metres in diameter with a pile depth below the seabed in the region of 15 to 50 metres. Jacket type substructures tend to be less common than monopiles and tend to have longer pile depths than monopiles.

Floating wind is a developing technology with a number of substructure designs being considered. Figure 4.2 shows the 3 most advanced designs currently being used with offshore construction (tension leg platform, spar buoy and semi-submersible). The tension leg platform design has the smallest mooring footprint while the spar buoy and semi-submersible designs have larger mooring radius requirements as they utilise taut, semi-taut or catenary mooring systems [10]. Two of the most recent floating offshore wind farms in the UK are the Hywind [11] and Kincardine [12] Offshore Floating Wind Farms in Scotland. The Hywind project is using a spar buoy substructure design with the Kincardine project using a semi-submersible substructure. Both projects are using ballasted catenary mooring lines as shown in Figure 4.3.

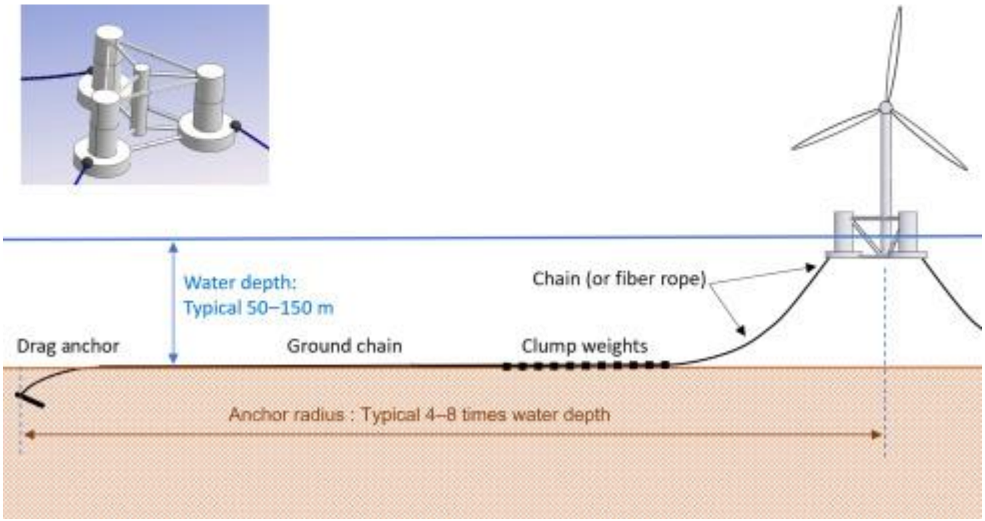

Figure 4.3: Typical Spread Mooring Design with Catenary Lines [13]

The mooring line radius for a catenary design is dependent on the water depth and is typically around 4 – 8 times the water depth, although it is noted that the maximum mooring radius on the Kincardine project is quoted to be 9 times the water depth [12]. Using this data, a typical "mooring radius" of circa 240 to 540 metres for a floating wind turbine installed in a water depth of 60 metres could be expected.

4.1.3 Typical Offshore Wind Infrastructure

The typical infrastructure that would be installed for an Offshore Wind project would be as follows:

- Wind turbines: Arranged in an array or a grid pattern (circa 5 to 175 turbines).
- Subsea array cables: Linking each wind turbine back to a central substation platform. Cables tend to be installed in a "daisy chain" arrangement, so that multiple turbines can feed into each cable.
- Offshore substation: To gather the power generated by the wind turbines and step it up to minimise power losses before being exported to shore. There will generally be one substation per wind farm but depending on the size of the site there could be two or more substations.
- High voltage subsea export cables: Linking the offshore substation(s) to shore.
- Onshore substation: Power is collected from offshore and supplied into the national grid. The national grid then converts to the voltage that matches the transmission network.

Figure 4.4 shows the typical high-level infrastructure for an Offshore Wind project:

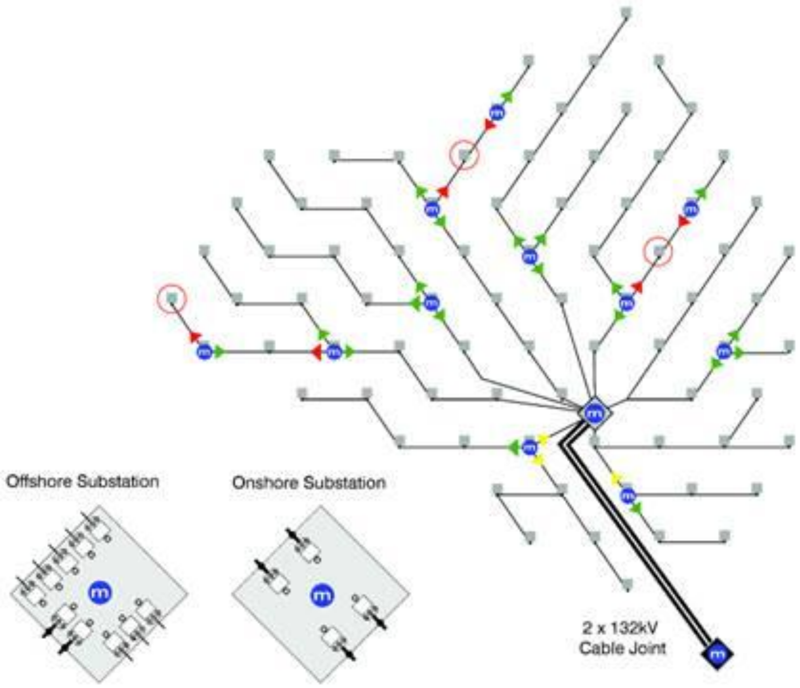

Figure 4.4: Typical Offshore Wind Project Infrastructure Arrangement

4.1.4 Offshore Wind Project Lifecycle

Each Offshore Wind project will typically consist of the following project lifecycle stages [14]:

Development	Installation & Commissioning	Operations & Maintenance	Decommissioning
~3 to 13 years	2 years	25 to 45 years	2 years
Site selection Site survey	Wind farm scheme development Facilities construction	Power generation Inspection and maintenance of facilities Site survey	Decommissioning planning Facilities removal

Figure 4.5: Indicative Offshore Wind Project Lifecycle Stages

Development

The purpose of this stage of an Offshore Wind project's lifecycle is to select the site for an Offshore Wind farm and perform all the project development and engineering works required to get full consent for the development.

The main offshore activities that will occur during this stage of the project's lifecycle include:

- Site surveys, including:

- Environmental surveys: Review of the potential impact on the environment, wildlife and human environment through the project lifecycle.
- Met ocean assessment: Provide atmospheric and oceanographic database to allow the engineering team to plan and design the wind farm. This may require the installation of a met mast and/or buoy.
- Geophysical surveys: Carry out surveys of the seabed, water depth, geotechnical investigations and soil stratigraphy as well as identifying natural and manmade hazards such as unexploded ordnance.
- Hydrographical surveys: Carry out a survey to examine how a wind farm will affect sedimentation and costal erosion.
- Archaeological surveys: Review the offshore site location for archaeological sites.

The above activities will generally be carried out by a marine survey vessel as shown below:

Figure 4.6: Typical Marine Survey Vessel

Figure 4.7 shows a typical met mast structure. These are installed at proposed wind farm sites to measure the wind speed and direction as well as meteorological data such as temperature, pressure and humidity over a period of time. The data needs to be collected all the way up to the hub height of the turbine so met masts can be quite tall (up to 100 metres above sea level). Met masts are installed with met ocean buoys to measure the wave and tidal data.

Figure 4.7: Typical Met mast Structure

In recent years, floating Lidar buoys have entered the market combining the met mast and met ocean buoys. They can be self-sufficient and installed easily and cheaply compared to their predecessors. The Lidar technology uses lasers directed into the sky to detect wind speed and direction up to 300 metres vertically and the buoy contains instrumentation to collect all the other information required for the design team such as wave height and direction.

Figure 4.8: Typical Floating Lidar Buoy [15]

Installation & Commissioning

The purpose of this stage of an Offshore Wind project's lifecycle is to develop and construct the overall offshore wind infrastructure.

The main offshore activities that will occur during this stage of the project's lifecycle include:

- Floating wind mooring line installation: Vessels dragging anchors into position with the mooring lines left on site awaiting the foundation to be pulled to site and connected.
- Floating turbine installation: Foundation will be constructed onshore and launched at a port. At this time, the turbine will either be assembled using an onshore crane and the foundation and turbine will be towed to site (Spar) or the turbine will be installed at site once the floating foundation (Semi-Sub & TLP) has been installed similar to static installation sequences using a heavy lift vessel.
- Static foundation installation: Heavy lift vessels, floating sheer-leg vessels and self-propelled jack-up vessels can all be used to install foundations.
- Offshore substation installation: Modules will be constructed onshore and a heavy lift vessel will install the module onto pre-installed foundations.
- Offshore cable installation: Cable laying/installation vessels will lay the cables on the seabed and remote operated vehicles will be involved in inspections and cable entry completion to structures.
- Turbine installation: Jack-up vessels will install the sections of the tower, nacelle and blades with the use of a crane onto pre-installed foundations.

- Rock placement: For stabilisation of cables where required.

Figure 4.9: Typical Cable Installation Vessel

Figure 4.10: Typical Jack-up Installation Vessel

Figure 4.11: Typical Operation to Tow Floating Wind Turbine to Site

Operations & Maintenance

The purpose of this stage of an Offshore Wind project's lifecycle is to operate and maintain the offshore wind power generation and transmission system.

The main offshore activities that will occur during this stage of the project's lifecycle include:

- Routine/minor maintenance & inspection: Crew transfer vessels travelling daily from shore with between 12-24 technicians, limited to 50 kilometres from port. Service operator vessels are larger vessels that are used for larger maintenance activities and can stay in the field for 4 weeks before refuelling with space for between 30 and 80 technicians. Helicopters can also be used for transferring technicians to and from turbines from an offshore platform or onshore base.

- Major maintenance: Service operator vessels are typically used for major maintenance campaigns, but jack-up vessels are required to replace large components such as rotor blades.
- Inspections of foundations and subsea components: Remote operated vehicles will be launched and controlled from a crew transfer or service operator vessel for inspection duties. Inspection of above water elements of the foundations may be inspected by rope access technicians transferred onto the asset from a crew transfer vessel.
- Inspections on array and export cables: Remote operated vehicles are used for inspections and can be launched from service operation and crew transfer vessels but inspections will usually be carried out from cable laying/inspection vessels. Cable laying vessels are also capable of performing larger maintenance activities such as repair and replacement of the cables during planned shutdowns.
- Seabed surveys to assess scour: Inspections of the seabed can be carried out either by remote operated vehicles launched and controlled from a crew transfer or service operator vessel for seabed surveys or by crewed vessels fitted with relevant survey sensory equipment.

Typical images for these types of vessels used during this stage of the project's lifecycle are shown below:

Figure 4.12: Typical Service Operation Vessel with Walk-to-Work Platform

Figure 4.13: Typical Crew Transfer Vessel

Decommissioning

The purpose of the decommissioning phase of an Offshore Wind project's lifecycle is to remove as much of the infrastructure associated with the project as possible to meet the project's consent conditions.

The main offshore activities that will occur during this stage of the project's lifecycle include:

- Static turbine decommissioning: Jack-up vessels will decommission the sections of the blades, nacelle and tower with the use of a crane.
- Static foundation decommissioning: Heavy lift vessels, floating sheer-leg vessels and self-propelled jack-up vessels can all be used to decommission the foundations.
- Floating turbine decommissioning: Whole assembly will be towed to a port for decommissioning.
- Floating wind mooring lines: Vessels will remove the anchor and mooring line and be decommissioned at port.
- Cable decommissioning: Cable vessels will destruct sections of the cables on the seabed surface with assistance from remote operated vehicles but there is a chance that sections of the cable will be left in place to minimise seabed disturbance.
- Offshore substation decommissioning: Module will be removed by heavy lift vessel and decommissioned onshore.

4.2 CCUS

4.2.1 Introduction

CCUS captures CO_2 from power generation, low carbon hydrogen production and industrial processes, storing it deep underground where it cannot enter the atmosphere. This technology will be globally necessary, but no one country has yet captured the market. The UK has an unrivalled asset – our North Sea, that can be used to store captured carbon under the seabed. Developing CCUS infrastructure will contribute to the economic transformation of the UK's industrial regions, enhancing the long-term competitiveness of UK industry in a global net zero economy. It will help decarbonise our most challenging sectors, provide low carbon power and a pathway to negative emissions.

The UK continental shelf is estimated to hold over 78 gigatonnes of potential CO_2 storage capacity, contained within over 560 subsurface stores as illustrated in Figure 4.14 [16].

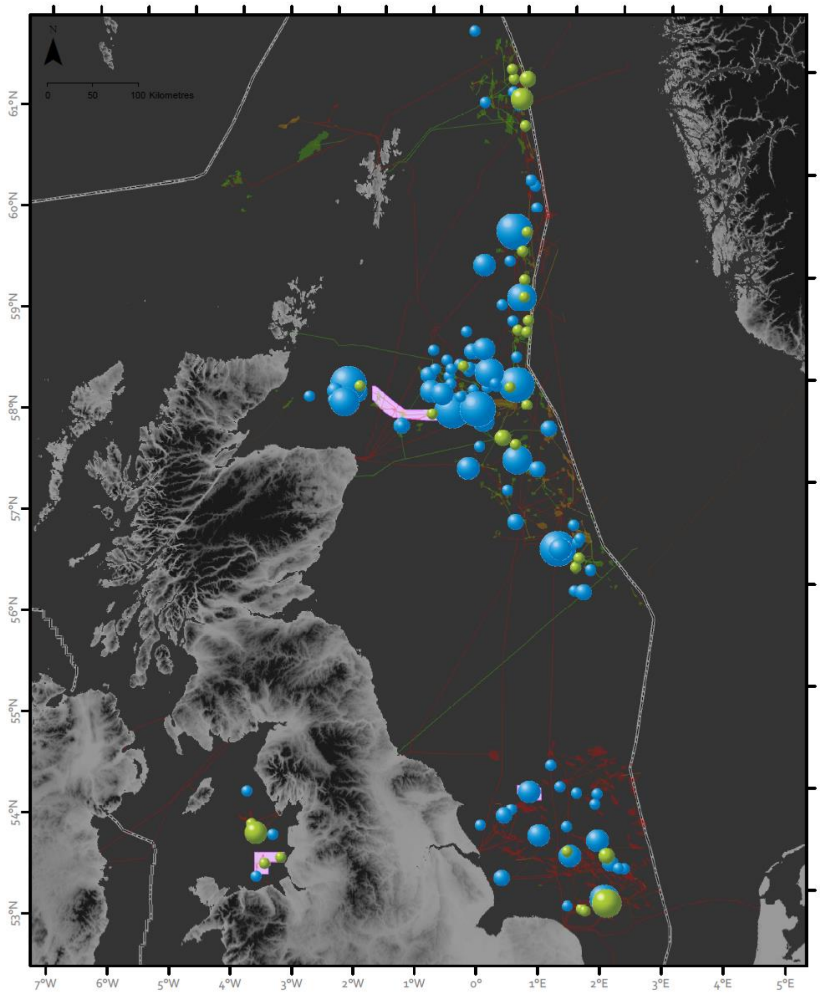

Figure 4.14: Map of Potential UK Offshore CO_2 Storage Sites [16]

This capacity could potentially cover the UK's carbon storage need for 100s of years and gives the potential for the UK to provide carbon storage services to other sources worldwide, providing significant value to the UK's economy.

The UK government aims to establish CCUS in approximately four main industrial clusters by 2030, enabling capture of up to 10 megatonnes of CO_2 per year. By developing these sites alongside hydrogen, there is potential to create transformative "SuperPlaces" in areas such as the heart of the North East, the Humber, North West and in Scotland and Wales. To support this, the UK government has established a £1billion CCUS Infrastructure Fund to provide industry with the certainty required to deploy CCUS at pace and at scale. It is anticipated that these clusters will be the starting point for a new carbon capture industry, which could support up to 50,000 jobs in the UK by 2030, including a sizeable export potential [17] [18] [19] [20].

The work carried out as part of this study is focused around the use of offshore geological storage sites in the UK continental shelf.

4.2.2 CCUS Storage Types

Two main types of geological storage site are likely to be used for CCUS in the UK:

- Saline aquifers: Porous and permeable formations that contain saline water. These formations will generally cover large areas (in the order of several tens of kilometres across) and CO_2 will be stored by displacing water from the storage formation.
- Depleted hydrocarbon reservoirs: Formations from which hydrocarbons have previously been produced. This type of store usually has a smaller area than saline aquifers (in the order of a few to a few tens of kilometres across) and the CO_2 will be stored by effectively filling up the space left in the formation from the previously produced hydrocarbons.

Figure 4.15 illustrates the potential volumes of CO_2 that could be stored within each of these storage types within the UK's offshore basins:

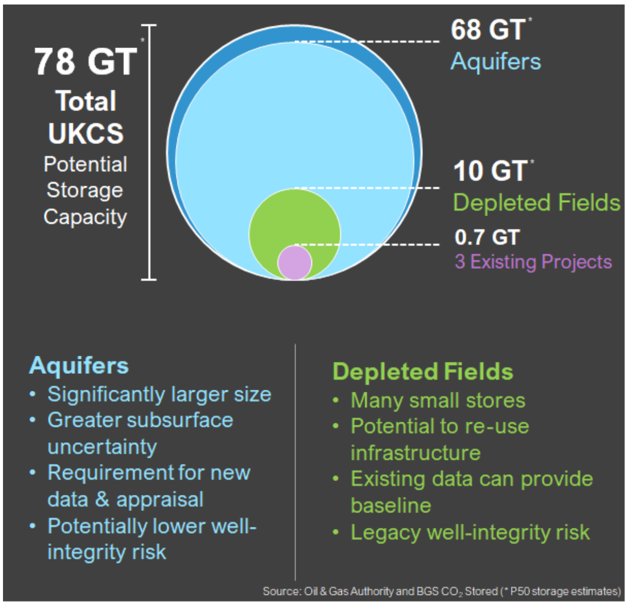

Figure 4.15: UK Offshore CO_2 Storage Potential for Main Types of Geological Storage [16]

The CO2Stored.co.uk database and ETI strategic appraisal report [16] summarises the key store parameters of over 500 potential saline aquifer and depleted field storage sites in the UKCS. The key characteristics of each type of storage site are summarised in Table 4.1.

Characteristic	Saline Aquifer	Depleted Hydrocarbon Reservoir
Storage Description	Large porous rock formations that are overlain with a low permeability layer that prevents upward migration of CO_2. Saline aquifers tend to not be "tightly constrained" and bulk storage of CO_2 generally involves displacement of saline water to other, hydraulically connected, formations plus a small pressure rise. The initial pressure within the storage site is approximately equivalent to the hydrostatic head for the formation depth, which results in CO_2 being stored as a "dense phase gas", which is equivalent to a low viscosity liquid with a density that is greater than saline water at the storage conditions. There may be a requirement for small or "tight" saline aquifers to drill brine release wells to limit the pressure rise in the aquifer due to CO_2 injection but it is likely that the majority of CCUS schemes will plan to utilise aquifers where this is not required and would likely only be required if the aquifer does not respond as expected to CO_2 injection.	Depleted hydrocarbon reservoirs are similar to saline aquifers in geology but tend to be smaller and more constrained. The pressure within such reservoirs at initial injection will tend to be significantly lower than saline aquifers due to previous production of hydrocarbons from the formation, resulting in CO_2 being stored as a gas at initial conditions. The storage mechanism for hydrocarbon reservoirs will tend to be mainly by pressurisation of the reservoir rather than displacement of reservoir contents to an adjoining formation. As a result, the pressure within the reservoir will rise over time with CO_2 transitioning to being stored as a "dense phase gas" at latter stages of injection. It is highly unlikely that any brine release wells would be required for CO_2 storage in depleted hydrocarbon reservoirs.
Formation Depth	Generally, between circa 1,000 and 2,500 metres below seabed level.	Tend to be deeper than saline aquifers with a typical formation depth of between 2,000 and 3,500 metres below seabed level.
Seabed Footprint	A large volume of reservoir per amount of CO_2 injected is required for saline aquifers due to their storage mechanism and initial reservoir conditions, resulting in a large seabed footprint being required.	Depleted hydrocarbon reservoirs can store significantly more CO_2 per unit reservoir volume than saline aquifers resulting in a smaller seabed footprint for such stores.
Well infrastructure	The long history of hydrocarbon exploration drilling in the North Sea means that plugged and abandoned legacy wells may penetrate a saline aquifer formation sitting above a deeper hydrocarbon exploration target. Such wells are generally fairly widely spaced and it is usually possible to avoid injection into the immediate area. The risk of stored CO_2 leaking from existing well infrastructure is therefore less for a saline aquifer than for depleted hydrocarbon reservoirs.	By their nature, depleted hydrocarbon reservoirs will have a number of existing wells drilled into them. While these wells will have been plugged and abandoned after their use in line with the requirements for oil and gas developments, there may be concerns with whether the abandonment measures would be suitable for exposure to CO_2, resulting in a higher potential for leaks from depleted hydrocarbon reservoirs than saline aquifers.

Characteristic	Saline Aquifer	Depleted Hydrocarbon Reservoir
Characterisation Requirements	Saline aquifers tend to require a significant amount of survey and study work to determine their suitability for storing CO2 and their potential storage capacity. As a result, the site activities required to characterise saline aquifers will tend to require extensive surveys and appraisal well drilling.	The geology, extent and trapping mechanisms for depleted hydrocarbon reservoirs are very well known given their previous operational history of producing hydrocarbons. As a result, the site characterisation requirements for understanding the store's potential for storing CO2 may be significantly less than those required for saline aquifers and may be limited to local seabed surface geophysical surveys. It is also highly unlikely that any appraisal well drilling would be required for depleted hydrocarbon reservoirs.

Table 4.1: Characteristics of CCUS Storage Site Types

4.2.3 Typical CCUS Infrastructure

The typical offshore infrastructure that would be installed for a CCUS scheme would be as follows:

- A pipeline to link the shore "sources" of CO2 to the offshore storage site.
- A set of wells to enable injection of CO2 into the storage site with their associated wellheads and surface piping and control systems (either installed on the seabed or on a small platform structure similar to the unmanned "wellhead platforms" used in the upstream oil and gas industry).
- A communications and power "umbilical" linking the control systems onshore to the offshore storage site.
- Monitoring, measurement and verification (MMV) facilities at the storage site.

The following figure illustrates a potential overall arrangement of a CCUS scheme:

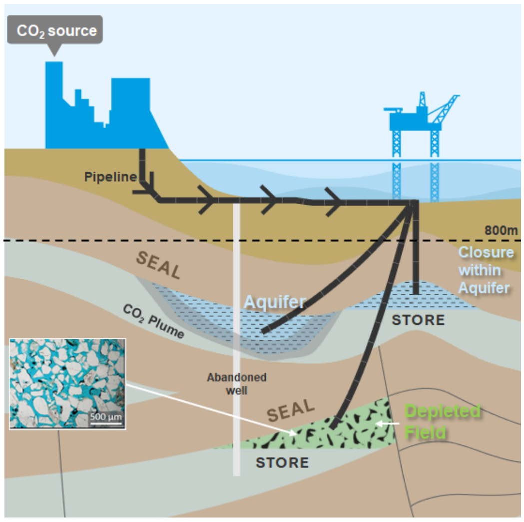

Figure 4.16: Typical CCUS Project Schematic

In terms of physical size, a typical subsea injection well for CCUS would have a seabed footprint in the range of 10 metres (width) × 10 metres (length) × 6 metres (height) with an associated manifold that would distribute CO_2 to individual wells in the region of twice the above footprint.

The following figure illustrates a typical subsea manifold and associated wells:

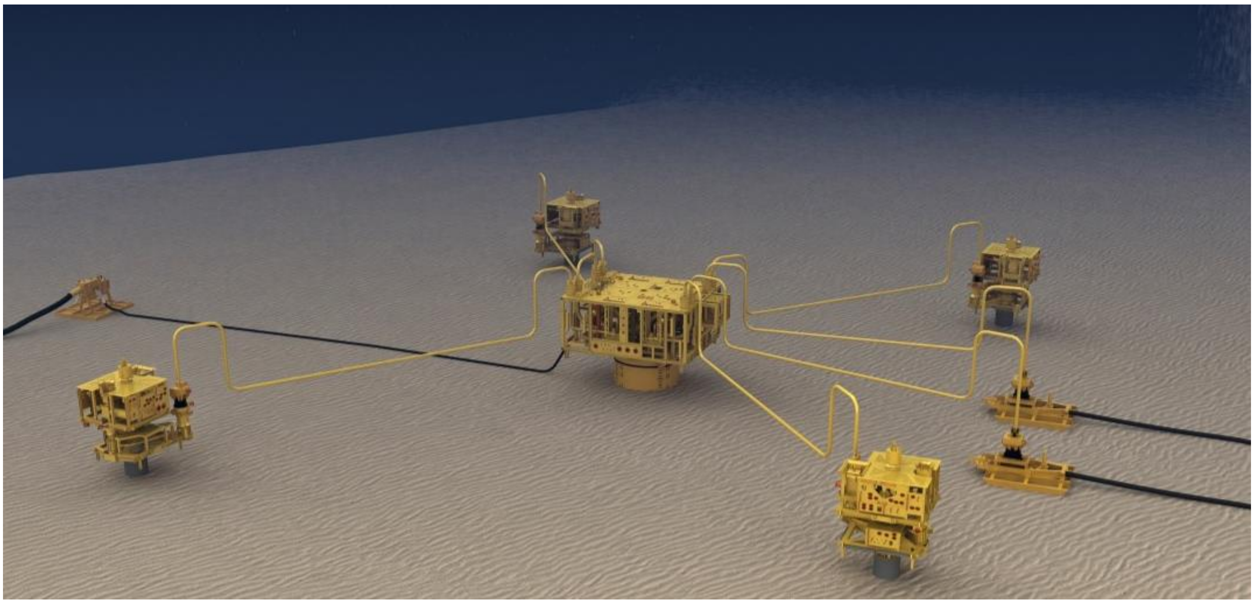

Figure 4.17: Typical Subsea Manifold and Wells

In comparison, a typical wellhead platform (new rather than re-use of an existing oil and gas platform) would typically have a seabed footprint in the region of 25 metres (width) × 25 metres (length) and would have a height sufficient to ensure that all facilities clear the 100 year peak wave zone in the area.

The following figure illustrates a typical wellhead platform:

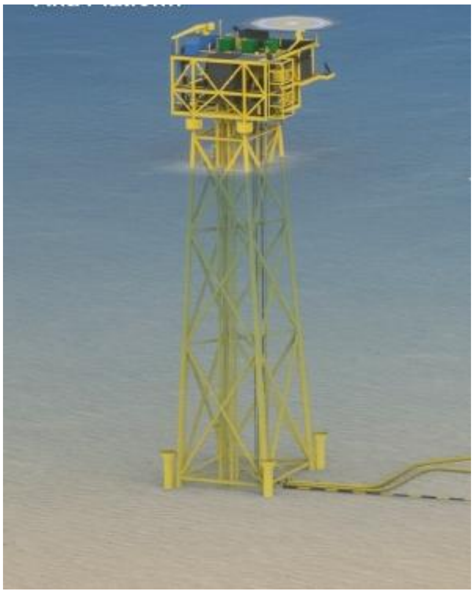

Figure 4.18: Typical Wellhead Platform

It is noted that operational zones (with a 500-metre radius based on analogue oil and gas projects) are required around the injection infrastructure.

A typical number of initial wells for both types of development would be less than 10 per CCUS store.

4.2.4 CCUS Project Lifecycle

Each CCUS project will typically consist of the following lifecycle stages:

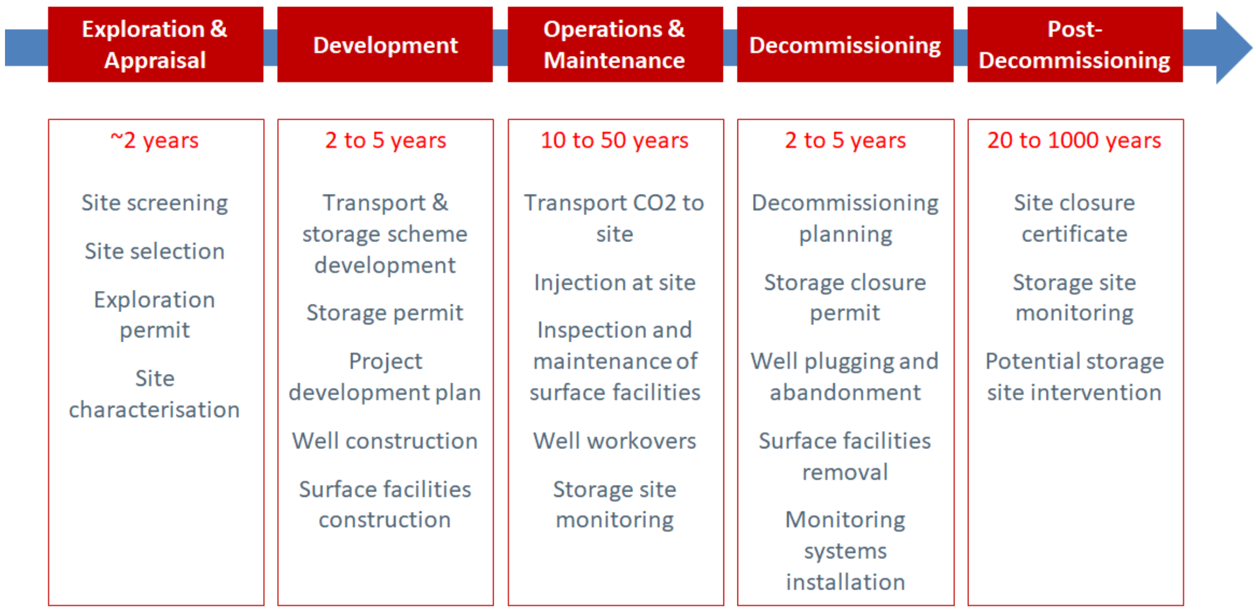

Figure 4.19: Indicative CCUS Project Lifecycle Stages

Exploration & Appraisal

The purpose of this stage of a CCUS project's lifecycle is to find an appropriate storage site for CCUS and then to gather sufficient information to allow the storage capabilities of the site to be adequately understood before committing to building a CCUS project.

The main offshore activities that will occur during this stage of the project's lifecycle include:

- Seismic surveys to gain an understanding of the geology of the storage site (e.g.towed streamer 3D seismic survey as shown in Figure 4.20).
- Site surveys to determine the local seabed conditions at the storage site (e.g. seabed sampling, cone penetration tests of seabed strength, etc.).
- Site surveys to determine the environmental conditions and local flora/fauna in the area.
- Drilling of exploration wells to provide input to studies to determine the storage site capability assessments. It should be noted that this would likely not be required for depleted hydrocarbon reservoirs as the previous production of hydrocarbons will have provided enough historical information to fully characterise the storage site's capabilities.

- Shallow hazard assessment of drilling sites using high resolution 2D towed streamer seismic surveys.

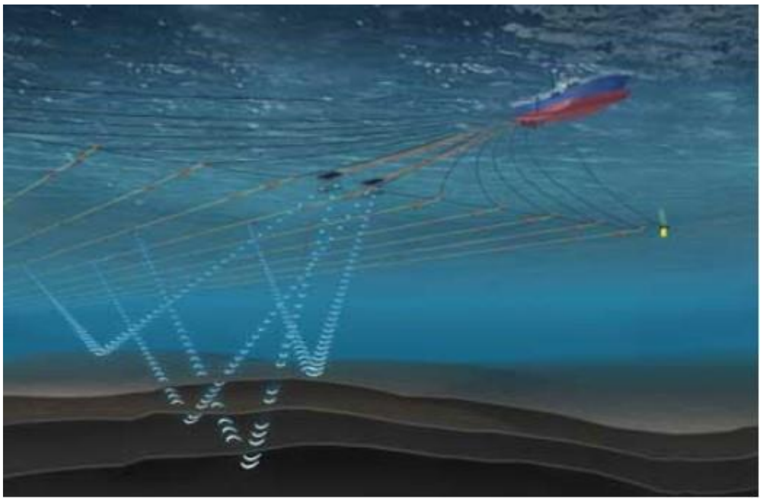

Figure 4.20: Typical "Towed Streamer" Seismic Survey Arrangement

Development

The purpose of this stage of CCUS project's lifecycle is develop and construct the overall offshore transportation and storage system.

The main offshore activities that will occur during this stage of the project's lifecycle include:

- Geophysical surveys (e.g. seabed sampling, cone penetration tests, etc.) at drill centres and along pipeline routes.
- Environmental baseline surveys at drill centres and along pipeline routes.
- Shallow hazard assessment of drilling locations using high resolution 2D towed streamer seismic surveys.
- Drilling of wells for CO2 injection and, in some cases for saline aquifers, brine pressure release wells
- Potential repair / upgrade of wells previously drilled into the storage site to ensure that they do not present a significant leakage risk from the storage site.
- Installation of pipelines, cables, offshore structures, etc. required to support overall transportation and storage scheme.
- Installation of MMV facilities at the storage site.

The above activities will typically be carried out by S-lay type pipeline installation vessels, umbilical installation vessels, dive support vessels, construction support vessels, drilling rigs, heavy lift vessels (for wellhead platforms) and survey vessels. Typical images for these types of vessels are shown below:

Figure 4.21: Typical S-lay Pipeline Installation Vessel

Figure 4.22: Typical Long Distance Umbilical Installation Vessel

Figure 4.23: Typical Semi-Submersible Drilling Rig

Figure 4.24: Typical Heavy Lift Vessel

Figure 4.25: Typical Construction Support Vessel

Figure 4.26: Typical Dive Support Vessel

Figure 4.27: Typical Survey Vessel

Operations & Maintenance

The purpose of this stage of CCUS project's lifecycle is operate and maintain the CO_2 transportation and storage system.

During this period, CO_2 will be transported through the infrastructure installed during the development phase and injected into the reservoir. The CO_2 will typically be captured and conditioned upstream of the transportation and storage system and will be high purity (i.e. nearly 100% CO_2), dry and with minimal contaminants. For the majority of CCUS schemes utilising offshore pipelines, the CO_2 will be transported as a dense phase gas at pressures in the region of 80-100 barg. There is the potential for lower operating pressures for "near-shore" CCUS schemes that intend to inject into depleted hydrocarbon reservoirs, but these will tend to be by exception rather than being a common occurrence.

The main offshore activities that will occur during this stage of the project's lifecycle include:

- Regular inspection of surface facilities associated with transportation and storage scheme (which may consist of vessels, remote-operated vehicles and helicopter operations depending on scheme development).
- Potential placement of rock to remediate the growth of spans underneath pipelines (due to scour).
- Potential work-over of injection wells (also potential requirement to drill intervention wells in the event of a leakage issue).
- Regular surveys (such as towed streamer 3D seismic and/or on-bottom node seismic) as part of the MMV scheme for the storage site.

The above activities will generally be carried out by dive support vessels, survey vessels and light-well intervention vessels (for well work-over). An image of a typical light well intervention vessel is shown below.

Figure 4.28: Typical Light Well Intervention Vessel

Decommissioning

The purpose of the decommissioning phase of a CCUS project's lifecycle is to plug and abandon the project's wells and then remove as much of the infrastructure associated with the project as possible.

The main offshore activities that will occur during this stage of the project's lifecycle include:

- Environmental and physical condition survey of storage site and all associated transportation and storage infrastructure.
- Well plugging and abandonment.
- Removal and recycling of surface facilities.
- Cleaning and leaving in-situ for large pipeline infrastructure.
- End remediation and burial for long cable / umbilical infrastructure.
- Potential installation of long-term "post closure" MMV facilities.

The above activities will generally be carried out by dive support vessels, survey vessels and light-well intervention vessels or drilling rigs (for well plugging and abandonment).

Post-Decommissioning

The purpose of the post-decommissioning phase of a CCUS project's lifecycle is to perform monitoring of the CO_2 store for an extended period following "closure" of the store to ensure that the CO_2 that was injected remains securely stored within the geological formation.

The regulations governing CCUS projects mandate that the responsibility for the storage site remains with the storage site operators until:

- When all available evidence indicates that the stored CO_2 will be completely and permanently contained; or
- A minimum period of 20 years has elapsed.

Following this, the responsibility for the storage site should be transferred to the state.

Prior to this transfer of responsibility, the main offshore activities that will occur during this stage of the project's lifecycle include:

- Less frequent (than the previous phases) surveys as part of the MMV scheme for the storage site.
- Potential for intervention wells needing to be drilled if there is a leak from the storage site.

The above activities will generally be carried out by survey vessels with drilling rigs required if an intervention well needs to be drilled in the event of a leak.

4.2.5 Monitoring, Measurement and Verification

Requirements

Monitoring, measurement and verification (MMV) plays a vital role in ensuring CO_2 storage meets operational, regulatory and community expectations with respect to containment, conformance and confidence across the store and the storage complex.

The MMV requirements over the lifecycle of a CCUS project can be broadly split into the following main phases:

- Exploration & Appraisal: Determining where the CCUS store should be and "characterising" the store to understand how it will react to injection of CO_2.
- Development: Making sure that a fixed baseline is obtained to allow the future performance of the CCUS store to be accurately monitored.
- Operations & Maintenance: Monitoring how the CCUS store reacts to injection of CO_2 to validate the modelled response and update models if required, monitoring of how the CO_2 propagates through the store to ensure that it doesn't migrate into other subsurface areas and monitoring of the store for potential leaks to surface.
- Decommissioning and Post-decommissioning: Monitoring of the store to give assurance that the CO_2 is contained within the planned storage area and that there are no leaks to surface for a defined period of time following cessation of injection (in the order of 20 years).

A wide range of technologies can be applied during each of the above stages in the lifecycle of a CCUS project. The technologies can be broadly categorised as being applicable to one or more of the following areas of assessment:

- Capacity: Initial site assessment of store volume and geological characteristics, monitoring injection pressure, flowrate and volume per well for evaluation of conformance to the predicted storage capacity. It is noted that this is sometimes referred to as part of monitoring the "confidence" of the injection site's performance.
- Containment: Monitoring to show that injected CO_2 is securely retained within the storage site with no unexpected migration beyond the primary storage reservoir.
- Injectivity: Monitoring injection pressure and flowrate per well to determine indicators of well performance for ease of accepting fluids. It is noted that this is sometimes referred to as part of monitoring the "confidence" of the injection site's performance.
- Contingency: Monitoring to characterise and track any potential undesired migration or system deviation. It is noted that this sometimes referred to as part of assessing the "conformance" of the injection site.

- Mitigation: Monitoring to track and quantify the effectiveness of mitigation measures to control any potential undesired migration or system deviation. It is noted that this sometimes referred to as part of assessing the "conformance" of the injection site.
- Public acceptance: Monitoring tools to ensure safe storage and system integrity; beneficial for increased public acceptance among the local population.

As is evident from the above list of categories, they are focused on the operations & maintenance, decommissioning and post-decommissioning phases of a CCUS project (i.e. once CO_2 has been injected into a store). While this doesn't include the exploration & appraisal plus development phases of a CCUS project, the technologies required for these phases are generally also applied in the operations & maintenance, decommissioning and post-decommissioning phases.

Solutions

Numerous studies have been carried out into the range of technologies available for CCUS MMV schemes. A wide ranging study on this subject has been carried out by the International Energy Agency [21], which was focused on developing an understanding of where future research efforts in CO_2 storage technologies should be focused on in the next decade, informing the potential directions for future research in order to fully maximise the potential benefits of storage technologies to commercial-scale CCS projects. The overall findings of this study are summarised in the table included in Appendix 2

In addition to describing and classifying technologies, [21] also reviewed the technology readiness level (TRL) of each technology with regards to its use as part of a CCUS MMV scheme. It is important to note that the TRLs were assessed purely on the use of technology on CCUS MMV schemes and not on the availability/readiness of each technology in general, so this does result in some technologies having a lower than otherwise expected TRL due to their lack of use on CCUS MMV schemes to date.

A range of TRL scales were used but this report has utilised the assessment of available technologies against European Commission TRLs for the Horizon 2020 funding. [22]:

- TRL 1: Basic principles observed.
- TRL 2: Technology concept formulated.
- TRL 3: Experimental proof of concept.
- TRL 4: Technology validated in lab.
- TRL 5: Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies).
- TRL 6: Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies).
- TRL 7: System prototype demonstration in operational environment.

- TRL 8: System complete and qualified.
- TRL 9: Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space).

Appendix 2 contains information extracted from [21] regarding the range of MMV technologies available, their TRLs and their applicability to offshore CCUS schemes and each stage of a typical CCUS project's lifecycle.

The key requirements for store characterisation and MMV at the above stages, current and future technologies available for achieving those requirements is summarised in Table 4.2.

Stage	Objective of store characterisation and MMV Activity	Current Technologies	Future Technologies / Best practice

Exploration & Appraisal
Required to assess the suitability of the geological storage location and characterise the storage capacity as well as to establish the pre-injection condition of the seabed and store
	• Locate potential store and map its extent	• Towed streamer 3D seismic survey
		• Assess data from existing wells
		• Regional geological evaluation
			• Minimise requirement for new seismic surveys by:
			  ○ New efficient methods of re-processing
			  ○ Cloud computing to maximise use of existing data
			  ○ New imaging algorithms
			  ○ Low cost on-bottom node seismic

	• Determine the geology of the store and overburden	• Exploratory and/or appraisal wellbore drilling to gather wireline logs, core and formation fluid data and samples (saline aquifer) • Evaluation of existing public domain wellbore data (depleted field storage)	• Innovative use of legacy data to evaluate store without requirement for new wells
	• Determine whether seabed has pre-existing leaks / seepage	• Sonar seabed surveys • Seabed physical survey and area environmental survey • High resolution 2D shallow seismic	• Routinely establish background gaseous seep incidence before injection starts
	• Determine seabed characteristics	• Seabed physical surveys	• High resolution seabed bathymetry mapping to assess pre-injection baseline plume development • Automated soil assessment • Remotely operated sampling and measurement
Development	• Measure and describe store's pre-injection conditions against which injection performance can be compared (for conformance purposes)	• 3D seismic survey	• 2D and 3D surface seismic • Lower cost acquisition of on-bottom node baseline • Seabed seismic sources
	• Data gathering in development wells at injection sites	• Wireline logging, cores, fluid pressure measurements and sample gathering	• Borehole EM • Cross well seismic

Stage	Objective of store characterisation and MMV Activity	Current Technologies	Future Technologies / Best practice
	• Plan and construct wells to deliver optimal injection performance	• Modified from oil and gas wells state of the art	• Alternatives to Portland cement • CO2 compatible construction materials • Cold well design • Plan ahead for optimised CO2 abandonment
	• Determine baseline environmental and geophysical conditions at injection site	• Seabed physical survey and area environmental survey	• Land ERT
Operations & Maintenance	• Monitor injection well performance versus predicted (modelled) performance	• In-well pressure and temperature monitoring • Metering of injected fluids	• Downhole sensing • Improve ability to meter CO2 • Cold well components
	• Monitor progression of CO2 through store (capacity), including comparison of observed versus predicted distribution	• Seismic survey (surface, passive, downhole)	• Wellbore seismic • Airborne spectral imaging
	• Monitor store for containment, including comparison to pre-injection condition to verify expected performance	• Micro-seismic survey, seabed geophones, gravity field monitoring, downhole distributed acoustic sensing, seabed bathymetry monitoring	• Enhance use of existing technology, proven for O&G applicability
	• Monitor seabed and injection wells for leaks (contingency and mitigation)	• Tracer chemical monitoring in local seawater, seabed bubble formation monitoring (acoustic sensing), sediment grab samples	• No identified additional future technologies / best practice
Decommissioning & Post-decommissioning	• Confirm CO2 remains contained in store (capacity)	• Seismic survey (surface, passive)	• Airborne spectral imaging
	• Monitor store for containment	• Seabed geophones, gravity field monitoring, seabed bathymetry monitoring,	• Enhanced use of existing technology
	• Monitor seabed and abandoned wells for leaks (contingency and mitigation)	• Tracer chemical monitoring in local seawater, seabed bubble formation monitoring (acoustic sensing), sediment grab samples	• Alternative barrier materials • Alternatives to Portland cement

Table 4.2: MMV Requirements and Current Technologies

From the information shown above and contained within Appendix 2 , it can be concluded that a wide range of technologies are either available or emergent to meet the capacity, containment, injectivity, contingency, mitigation and public acceptance requirements for CCUS MMV schemes.

However, prior to commencement of injection (i.e. during the exploration & appraisal plus development stages of a CCUS project), there is an over-arching requirement to understand the size, scale and capacity of the CCUS store.

The European Union CCS directive [23] requires that the storage complex is the key volume that needs to be defined prior to implementation of a CCUS project. The requirements are that sufficient data is accumulated to construct a volumetric and three-dimensional static (3D)-earth model for the storage site and storage complex, including the caprock, and the surrounding area, including the hydraulically connected areas.

The following are expected to be either essential or dominant for future projects:

- Geological site characterisation datasets are essential and will typically include several wells (with an extensive logging and coring programme), surface surveys and 3D seismic surveys covering the site volume.
- Standard wellhead and downhole measurements (regular or continuous measurement of pressure, temperature and fluid composition).
- Time-lapse seismic monitoring (with many options on the type of seismic acquisition and repeat intervals).
- Distributed fibre-optic sensing, both downhole and at surface.
- Monitoring rock strain and microseismic events, using either purposed arrays of 3-component geophones or surface deformation monitoring.
- Gravity field monitoring, especially for larger offshore projects.
- Surface gas monitoring (with quite different strategies for onshore and offshore settings).

Current practice is to characterise a potential CCUS store using a combination of 3D seismic survey and wellbore data and sampling to enable representative models of the store to be built. The most cost-effective method of 3D seismic data acquisition is by towed streamer. This involves towing an array of seismic sensors behind a survey vessel (typically measuring in the order of 3 to 6 kilometres in length and 500 metres to 2 kilometres in width) at a depth of approximately 10 metres below sea surface with an acoustic source also towed, closer behind the vessel, 3 to 4 metres below sea surface (Figure 4.20).

It is noted that this size is indicative and may be smaller when considering relatively shallow reservoirs or different seafloor substrates but further study is required to define the degree to which this may apply.

The survey grid must have a very accurate positioning and regularity to give sufficient coverage of the area of the store and also requires a wide turning circle for re-positioning of the survey vessel and streamer array as it moves along the pre-defined grid.

The use of such an array makes it unfeasible to overlap towed streamer seismic acquisition with Offshore Wind projects, where the turbine spacing of circa 1.3-2.2 × 0.9-1.8 kilometres (discussed in section 4.1.1) makes it highly likely that the array will snag on wind turbine substructures.

Alternative seismic survey technologies are available, e.g. on-bottom node, that reduce the dependency on such long cable arrays for gathering seismic data. On-bottom node seismic surveying still requires the towing of seismic source along a very accurately positioned, regular grid that covers the entire reservoir footprint. This is regarded to be only feasible in the presence of Offshore Wind infrastructure if it is meticulously planned in advance to run safely between and around Offshore Wind infrastructure. Furthermore, the effects of Offshore Wind turbine foundations and background noise on the quality of the seismic data gathered will need to be understood and managed. This type of survey has a significantly higher cost than towed streamer acquisition and is not as suitable for surveying wide areas as may be required for the exploration & appraisal stage of a CCUS project's lifecycle. This risk and its potential mitigation measures are further discussed within the remainder of this document.

5 Risks

A series of workshops were held with the participation of a wide range of stakeholders to identify the risks associated with overlapping Offshore Wind and CCUS projects across all stages of their individual project lifecycles.

This resulted in over 250 discrete risks being identified, which were then processed to assess common causes and consequences and to remove duplication. Following processing, an aggregated list of 46 risks was produced.

Each risk on the aggregated list was then assessed to determine their likelihood and consequence over a range of areas, using the risk assessment matrix in Appendix 1 , to produce an overall "level" of impact for each risk prior to any mitigation measures being applied to manage those risks.

The aggregated list and assessment of risks is included in Appendix 3 . The assessment resulted in the following categories of risk level being identified:

- 16 risks classified as having a high impact.
- 26 risks classified as having a medium impact.
- 4 risks classified as having a low impact.

Table 5.1 illustrates the number and impact of risks that apply to the overlap of Offshore Wind and CCUS projects at each stage of their individual project lifecycles.

OFFSHORE WIND \ CCUS	Exploration & Appraisal	Development	Operations & Maintenance	Decommissioning	Post-decommissioning
Development	High = 4 Medium = 12 Low = 1	High = 4 Medium = 12 Low = 1	High = 4 Medium = 14 Low = 1	High = 3 Medium = 7 Low = 1	High = 2 Medium = 7 Low = 1
Installation & Commissioning	High = 5 Medium = 12 Low = 1	High = 7 Medium = 14 Low = 2	High = 9 Medium = 16 Low = 1	High = 7 Medium = 9 Low = 1	High = 3 Medium = 9 Low = 1
Operations & Maintenance	High = 5 Medium = 11 Low = 2	High = 7 Medium = 13 Low = 2	High = 11 Medium = 23 Low = 3	High = 8 Medium = 14 Low = 3	High = 4 Medium = 14 Low = 3
Decommissioning	High = 1 Medium = 4 Low = 1	High = 2 Medium = 6 Low = 1	High = 5 Medium = 14 Low = 2	High = 4 Medium = 11 Low = 2	High = 1 Medium = 11 Low = 2

Table 5.1: Summary of Identified Risks for Offshore Wind and CCUS Over Project Lifecycle
Note: Table shows risk impact levels and number of risks per project overlap stage.

As can be seen from Table 5.1, the highest concentration of risks and risk impacts are around the overlap of the operations & maintenance phases for Offshore Wind and CCUS projects. The second "rank" of risk impacts occurs during the overlap of the development of new projects with ongoing operations. In comparison, overlapping of the decommissioning / post-decommissioning phases with the development or ongoing operations of projects represents a relatively low level of risk impact.

The following common elements categorise the majority (all but 2 of the medium impact risks) of the identified risk items across all project lifecycles and can be considered the main sources of potential risk for overlapping of Offshore Wind and CCUS projects:

A. A lack of clarity over how issues associated with overlapping of Offshore Wind and CCUS projects such as development planning / precedence, promotion of collaboration, alignment of standards, cross-industry liabilities and dispute mediation would be handled. (4 high impact risks, 7 medium impact risks, 2 low impact risks)
B. The requirement to perform MMV surveys (particularly seismic surveys) for CCUS projects across their lifecycle and the interaction with Offshore Wind infrastructure. (4 high impact risks, 1 medium impact risk, 1 low impact risk)

C. A higher level of offshore operations that result from locating two projects in the same area. (3 high impact risks, 6 medium impact risks, 1 low impact risk)

D. Direct physical impacts to infrastructure or personnel due to incidents occurring as a result of overlapping projects. (3 high impact risks, 4 medium impact risks, 0 low impact risks)

E. The physical infrastructure of a pre-existing project blocking access to the seabed or modifying the requirements for new projects. (2 high impact risks, 6 medium impact risks, 0 low impact risks)

The two medium impact risks not covered by the common elements are:

ID	Risk	Cause	Consequence
020	Risk of: Difficulty in gaining insurance cover	Due to: Inability to properly categorise and quantify risks for co-developed areas	Resulting in: Increased insurance premiums
034	Risk of: Lack of knowledge retention / lessons learned for SIMOPS	Due to: Long periods between installation and decommissioning activities for CCUS and Offshore Wind	Resulting in: Poor project execution

Table 5.2: Risks not Covered by Common Elements

6 Risk Mitigation Measures

6.1 General

Once the impact of the identified risks was assessed, the study considered the mitigation measures available now and potentially available in future to reduce the impact of the risks.

Another workshop was held with input from stakeholders to determine the potential mitigation measures applicable to each of the identified risks. Within the workshop, mitigation measures were classified as being:

- Good practice mitigation measures: Mitigation measures that can be applied now without further study or development based upon good practice across the Offshore Wind and CCUS industries as well as by transferring good practice from the upstream oil and gas industry.
- Future mitigation measures: Mitigation measures that could potentially be applied in future but require some further development or further study work to determine whether they are feasible and economic.

The following sections summarise the above mitigation measure classifications and their impact on the risks identified as arising from overlapping of Offshore Wind and CCUS projects.

6.2 Good Practice Mitigation Measures

The results of the impact of good practice mitigation measures are detailed in Appendix 4 .

The good practice mitigation measures that were identified had the following impact on the overall aggregated list of risks:

- Reduced the number of risks classified as having a high impact from 16 to 10.
- Reduced the number of risks classified as having a medium impact from 26 to 25.
- Increased the number of risks classified as having a low impact from 4 to 11.

Table 6.1 illustrates the impact of the identified good practice mitigation measures on the risks associated with the overlap of Offshore Wind and CCUS projects at each stage of their individual project lifecycles.

		CCUS				
OFFSHORE WIND		Exploration & Appraisal	Development	Operations & Maintenance	Decommissioning	Post-decommissioning
	Development	High = 3 Medium = 9 Low = 5	High = 3 Medium = 9 Low = 5	High = 2 Medium = 10 Low = 7	High = 1 Medium = 5 Low = 5	High = 1 Medium = 4 Low = 5
	Installation & Commissioning	High = 4 Medium = 9 Low = 5	High = 5 Medium = 12 Low = 6	High = 5 Medium = 15 Low = 6	High = 4 Medium = 8 Low = 5	High = 2 Medium = 6 Low = 5
	Operations & Maintenance	High = 4 Medium = 8 Low = 6	High = 5 Medium = 23 Low = 9	High = 5 Medium = 23 Low = 9	High = 4 Medium = 14 Low = 7	High = 2 Medium = 12 Low = 7
	Decommissioning	High = 0 Medium = 1 Low = 5	High = 0 Medium = 4 Low = 5	High = 1 Medium = 12 Low = 8	High = 1 Medium = 10 Low = 6	High = 0 Medium = 8 Low = 6

Table 6.1: Summary of Overall Lifecycle Risk Reduction with Good Practice Mitigations

As can be seen from the above table, the level of risk impact across all stages of the both Offshore Wind and CCUS project's lifecycles can be markedly reduced by the application of good, current practice. This is particularly the case across the installation/commissioning and operations/maintenance phases of Offshore Wind projects.

In terms of the underlying sources for the identified risks, good practice mitigation measures were assessed as having the following impact:

Common Element	Main Good Practice Mitigations	Reduction in Risk Impact from Good Practice Mitigations
A – Lack of clarity over business overlap issues	• Good co-ordination between overlapping project operators.	High = Remains the same at 4 Medium = Reduced from 7 to 6 Low = Increased from 2 to 3
B – Interaction with CCUS MMV surveys	• Plan survey timings to minimise interaction with existing infrastructure (e.g. don't coincide with major maintenance activities or power down infrastructure during surveys).	High = Remains the same at 4 Medium = Reduced from 1 to 0 Low = Increased from 1 to 2
C – Increased site operations	• Cross-industry co-ordination and engagement with supply chain. • Standard operational safety measures (with respect to helicopter and diver operations). • Good co-ordination between overlapping project operators (e.g. environmental monitoring, noise monitoring, sharing of resources, activity planning, etc.).	High = Reduced from 3 to 0 Medium = Remains the same at 6 Low = Increased from 1 to 4
D – Physical impacts / damage	• Use lessons learned from upstream oil & gas industry in relation to simultaneous operations, lifting plans, dropped objects, exclusion zones, "fish-safe" subsea structures, etc. • Ensure planning of infrastructure takes into account access requirements for co-located projects (e.g. for potential intervention wells on CCUS).	High = Reduced from 3 to 1 Medium = Increased from 4 to 6 Low = Remains the same at 0
E – Existing infrastructure blocking access	• Ensure planning of infrastructure takes into account access requirements for co-located projects.	High = Reduced from 2 to 1 Medium = Reduced from 6 to 4 Low = Increased from 0 to 3

Table 6.2: Impact of Good Practice Mitigation Measures on Common Elements of Identified Risks

The following current good practice measures were identified for the risks not covered by the common elements of identified risks:

ID	Risk	Cause	Consequence	Good Practice Mitigation
020	Risk of: Difficulty in gaining insurance cover	Due to: Inability to properly categorise and quantify risks for co-developed areas	Resulting in: Increased insurance premiums	None identified
034	Risk of: Lack of knowledge retention / lessons learned for SIMOPS	Due to: Long periods between installation and decommissioning activities for CCUS and Offshore Wind	Resulting in: Poor project execution	• Implement effective succession planning and knowledge retention within CCUS and Offshore Wind projects to avoid this - good corporate practice in any case • Implement lessons learned from oil and gas industry when assets have changed hands • Keep up to date records of drawings etc.

Table 6.3: Good Practice Mitigation Measures for Risks not Covered by Common Elements

As can be seen from the above tables, the identified current good practice measures are mainly based around good co-ordination and communication between overlapping project developers and across both industries in a wider sense plus applying lessons learned from the upstream oil and gas industry to mitigate against overlapping project site activities.

These measures mainly impact common elements C to E (plus risk 034), which are mainly associated with ensuring that overlapping projects consider each other's needs and activities. This is where the lessons learned through the long track record of the upstream oil and gas industry of co-ordination between project developers will be particularly valuable to the Offshore Wind and CCUS industries, including good engagement and collaboration with the supply chain for both industries.

In contrast, current good practice mitigations have minimal impact on the "top ranked" common elements A and B.

6.3 Future Mitigation Measures

The results of the impact of potential future practice mitigation measures are detailed in Appendix 5 .

The future practice mitigation measures that were identified had the following impact on the overall impact on the aggregated list of risks:

- Reduced the number of risks classified as having a high impact to 2 (compared with pre-mitigation = 16, good practice mitigation = 10).

- Reduced the number of risks classified as having a medium impact to 23 (compared with pre-mitigation = 26, good practice mitigation = 23).
- Increased the number of risks classified as having a low impact to 20 (compared with pre-mitigation = 4, good practice mitigation = 11).
- Reduced the impact level on 1 risk to very low.

Table 6.4 illustrates the impact of the identified potential future mitigation measures on the risks associated with the overlap of Offshore Wind and CCUS projects at each stage of their individual project lifecycles.

As can be seen from the table, the level of risk impact across all stages of both Offshore Wind and CCUS project's lifecycles can be significantly further reduced by the application of the identified future mitigation measures.

The application of the identified future mitigation measures has the potential to reduce the overall risk impact across all overlapping lifecycle stages to a level that is considered to be low compared to the pre-mitigation risk impacts apart from the overlap in the development / installation plus operations / maintenance phases and the overlap of Offshore Wind operations with CCUS decommissioning.

This demonstrates that there is significant benefit and value in investing in developing the potential future mitigation measures identified in this study to reduce the overall risk presented by overlapping Offshore Wind and CCUS projects.

		CCUS				
OFFSHORE WIND		Exploration & Appraisal	Development	Operations & Maintenance	Decommissioning	Post-decommissioning
	Development	High = 1 Medium = 7 Low = 9	High = 1 Medium = 7 Low = 9	High = 1 Medium = 7 Low = 11	High = 0 Medium = 5 Low = 6	High = 0 Medium = 4 Low = 6
	Installation & Commissioning	High = 2 Medium = 7 Low = 9	High = 2 Medium = 11 Low = 10	High = 2 Medium = 14 Low = 10	High = 1 Medium = 10 Low = 6	High = 1 Medium = 6 Low = 6
	Operations & Maintenance	High = 2 Medium = 5 Low = 11	High = 2 Medium = 9 Low = 11	High = 2 Medium = 16 Low = 18 Very low = 1	High = 1 Medium = 11 Low = 12 Very low = 1	High = 1 Medium = 7 Low = 12 Very low = 1
	Decommissioning	High = 0 Medium = 1 Low = 5	High = 0 Medium = 4 Low = 5	High = 0 Medium = 9 Low = 11 Very low = 1	High = 0 Medium = 7 Low = 9 Very low = 1	High = 0 Medium = 4 Low = 9 Very low = 1

Table 6.4: Summary of Overall Lifecycle Risk Reduction with Potential Future Practice Mitigations

In terms of the common elements for the identified risks, potential future practice mitigation measures were assessed as having the following impact:

Common Element	Main Potential Future Practice Mitigations	Reduction in Risk Impact from Potential Future Practice Mitigations
A – Lack of clarity over business overlap issues	• Consider appointing a common oversight body for overlapping Offshore Wind and CCUS projects, consisting of a combination of government and industry bodies, to handle provide input to enable issues such as overlap planning opportunities, development planning / precedence, promotion of collaboration, alignment of standards, cross-industry liabilities and dispute mediation to be handled. • Consider co-ordinating stakeholder management across overlapping projects. • Apply lessons learned from upstream oil & gas industry around decommissioning requirements.	High = Reduced from 4 to 0 Medium = Remains the same at 7 (c.f. 6 for good practice) Low = Increased from 2 to 5 (c.f. 3 for good practice) Very low = Increased from 0 to 1
B – Interaction with CCUS MMV surveys	• Consider appointing a common oversight body for overlapping Offshore Wind and CCUS projects, consisting of a combination of government and industry bodies, to handle provide input to enable issues such as overlap planning opportunities, development planning / precedence, promotion of collaboration, alignment of standards, cross-industry liabilities and dispute mediation to be handled. • Pro-actively review where Offshore Wind and CCUS projects could potentially overlap (i.e. where are the good CCUS stores versus the high potential Offshore Wind sites) and ensure a combined approach to planning in those areas. • Consider requiring Offshore Wind developers to perform CCUS suitable seismic surveys over the seabed area during development of their project. • Invest in development of alternative CCUS store characterisation and monitoring technologies that are compatible with Offshore Wind projects to replace the need for towed seismic surveys. • Review / re-process existing seismic data already held for the UK offshore area to determine where it might be suitable for characterising future CCUS stores without further seismic surveys. • Consider whether there is scope to relax requirements to "prove" CCUS stores as part of the permit application process. • Study the impact of noise and signal degradation caused by Offshore Wind on seismic monitoring results. • Determine whether the noise characteristics from Offshore Wind are similar to oil and gas operations and see if lessons can be learned from that industry. • Develop technology to use Offshore Wind "noise" as a source for seismic surveys.	High = Reduced from 4 to 2 Medium = Remains the same at 1 (c.f.0 for good practice) Low = Increased from 1 to 3 (c.f. 2 for good practice)

Common Element	Main Potential Future Practice Mitigations	Reduction in Risk Impact from Potential Future Practice Mitigations
	• Use existing oil and gas or Offshore Wind assets to test CCUS MMV methods; no need to wait for CCUS pilot projects. • Clearly define the "best practice" and "minimum acceptable practice" in terms of CCUS MMV schemes, through the regulator performing a review of current MMV requirements to minimise the need for seismic surveys in particular, and ensure that these are taken into account when planning overlapping CCUS and Offshore Wind projects on a case-by-case basis. • Develop a bespoke MMV strategy for overlap projects on a case-by-case basis. • Consider issuing a public period of notice for any new Offshore Wind or CCUS project to allow potential future overlapping project developers to co-ordinate with original project developer.	
C – Increased site operations	• Consider appointing a common oversight body for overlapping Offshore Wind and CCUS projects, consisting of a combination of government and industry bodies, to handle provide input to enable issues such as overlap planning opportunities, development planning / precedence, promotion of collaboration, alignment of standards, cross-industry liabilities and dispute mediation to be handled. • Ensure overlap access requirements in terms of helicopter operations are considered in project developments.	High = 0, no change from good practice Medium = 6, no change from good practice Low = 4, no change from good practice
D – Physical impacts / damage	• Consider ensuring that "high impact" alarms are shared between overlapping operators. • Study the potential for brine release to damage Offshore Wind infrastructure. • Study the potential for drilling / seismic survey work to damage Offshore Wind infrastructure. • Study potential impact of well release in more detail.	High = Reduced from 3 to 0 (c.f. 1 from good practice) Medium 6, no change from good practice Low = Increased from 0 to 1 (c.f. 0 from good practice)
E – Existing infrastructure blocking access	• Consider appointing a common oversight body for overlapping Offshore Wind and CCUS projects, consisting of a combination of government and industry bodies, to handle provide input to enable issues such as overlap planning opportunities, development planning / precedence, promotion of collaboration, alignment of standards, cross-industry liabilities and dispute mediation to be handled. • Pro-actively review where Offshore Wind and CCUS projects could potentially overlap (i.e. where are the good CCUS stores versus the high potential Offshore Wind sites) and ensure a combined approach to planning in those areas.	High = Reduced from 2 to 0 (c.f. 1 from good practice) Medium = Reduced from 6 to 2 (c.f. 4 from good practice) Low = Increased from 0 to 6 (c.f. 3 from good practice)

Table 6.5: Impact of Potential Future Mitigation Measures on Sources of Identified Risks

The following table illustrates the potential future practice mitigation measures for the risks that are not covered by common elements A to E.

ID	Risk	Cause	Consequence	Future Practice Mitigation
020	Risk of: Difficulty in gaining insurance cover	Due to: Inability to properly categorise and quantify risks for co-developed areas	Resulting in: Increased insurance premiums	• Mitigation is the outcome of this risk study and any follow-on studies into areas of "not easily" mitigated risk that are caused by co-location • Potential for a common oversight body or independent group to show active monitoring of risks and provide good communication to insurance industry
034	Risk of: Lack of knowledge retention / lessons learned for SIMOPS	Due to: Long periods between installation and decommissioning activities for CCUS and Offshore Wind	Resulting in: Poor project execution	• Potentially scope to hold a central "lessons learned" database for Offshore Wind and CCUS projects to enable best practice knowledge sharing

Table 6.6: Future Practice Mitigation Measures for Risks not Covered by Common Elements

As can be seen from the above tables, the following potential future mitigations apply across a number of the common elements of risks for overlapping Offshore Wind and CCUS projects:

- Consider appointing a common oversight body for overlapping Offshore Wind and CCUS projects, consisting of a combination of government and industry bodies, to provide input to enable issues such as overlap planning opportunities, development planning / precedence, promotion of collaboration, alignment of standards, cross-industry liabilities and dispute mediation to be handled.

- Pro-actively review where Offshore Wind and CCUS projects could potentially overlap (i.e. where are the good CCUS stores versus the high potential Offshore Wind sites) and ensure a combined approach to planning in those areas.

The application of the above future mitigations has the potential to significantly reduce the overall impact across the majority of the identified risks.

One major risk area that needs particular attention and future work is the interaction between the MMV requirements for developing, operating and decommissioning a CCUS project that overlaps with an Offshore Wind project. The main interaction risks identified for this area are:

- The space requirements for conducting a towed streamer seismic survey (the current "go to" technology for characterising a CCUS store and a potential major element of most MMV schemes for CCUS projects) not being compatible with the feasible grid spacing between turbines for Offshore Wind projects. It is not considered to be feasible to carry out a towed streamer seismic survey within the same area as an Offshore Wind farm based on current towed streamer technology and the required spacing for Offshore Wind infrastructure.

- Potential degradation of MMV survey information (mainly towed streamer or "on bottom node" seismic surveys) due to background noise from Offshore Wind operations and, potentially, signal interference from the foundations of fixed wind structures (turbines and substation platforms).

The potential future mitigation measures for these areas were identified as being:

- Pro-actively review where Offshore Wind and CCUS projects could potentially overlap (i.e. where are the good CCUS stores versus the high potential Offshore Wind sites) and ensure a combined approach to planning in those areas.

- Consider requiring Offshore Wind developers to perform CCUS suitable seismic surveys over the seabed area during development of their project – this would remove the need for towed streamer seismic surveys as part of the CCUS store characterisation process.

- Invest in development of alternative CCUS store characterisation and monitoring technologies that are compatible with Offshore Wind projects to replace the need for towed seismic surveys – this would assist in being able to use seismic surveys as part of the "operational" and post-decommissioning MMV schemes for a CCUS store and may enable towed streamer seismic technology to be replaced during the CCUS store characterisation process.

- Review / re-process existing seismic data already held for the UK offshore area to determine where it might be suitable for characterising future CCUS stores without further seismic surveys – this would reduce the need to perform new seismic surveys to characterise CCUS stores and therefore reduce the potential for towed seismic survey interaction with Offshore Wind developments during the CCUS store characterisation process.

- Consider whether there is scope to relax requirements to "prove" CCUS stores as part of the permit application process – this would potentially remove the need for towed streamer seismic surveys as part of CCUS store characterisation and MMV schemes.

- Study the impact of noise and signal degradation caused by Offshore Wind on seismic monitoring results – this will quantify whether there is an issue with survey quality associated with performing seismic monitoring in an area with Offshore Wind operations.

- Determine whether the noise characteristics from Offshore Wind are similar to oil and gas operations and see if lessons can be learned from that industry – this will assist in quantifying whether there is an issue with survey quality associated with performing seismic monitoring in an area with Offshore Wind operations

- Develop technology to use Offshore Wind “noise” as a source for seismic surveys – this would potentially remove the need for towed streamer seismic surveys as part of CCUS store characterisation and MMV schemes.

- Develop a bespoke MMV strategy for overlap projects on a case-by-case basis – this would optimise the MMV requirements and potentially minimise the interaction issues between Offshore Wind and CCUS projects.

- Use existing oil and gas or Offshore Wind assets to test CCUS MMV methods – this will assist in quantifying whether there is an issue with survey quality associated with performing seismic monitoring in an area with Offshore Wind operations.

- Clearly define the “best practice” and “minimum acceptable practice” in terms of CCUS MMV schemes, through the regulator performing a review of current MMV requirements to minimise the need for seismic surveys in particular, and ensure that these are taken into account when planning overlapping CCUS and Offshore Wind projects on a case-by-case basis.

The above recommended areas for future work on managing this particular risk area can be distilled down to the following:

- Pro-actively review where Offshore Wind and CCUS projects could potentially overlap and consider performing site characterisation activities in these areas prior to any Offshore Wind or CCUS project development.

- Clearly define the “best practice” and “minimum acceptable practice” in terms of CCUS MMV schemes, through the regulator performing a review of current MMV requirements to minimise the need for seismic surveys in particular, and ensure that these are taken into account when planning overlapping CCUS and Offshore Wind projects on a case-by-case basis.

- Provide government/regulator support for a future technology development campaign in reservoir characterisation and MMV to remove the dependency on new seismic acquisition (e.g. forward modelling of response of different reservoir types' rock physics response to CO_2 flood; what constitutes appropriate monitoring post-injection).

This is considered to be a crucial interaction area for the overlap of Offshore Wind and CCUS and it is recommended that industry and regulators seriously consider the above potential mitigations as they are all seen as key elements in enabling the potential co-location of such projects in future.

7 Opportunities

A number of potential opportunities available to improve the delivery and performance of overlapping Offshore Wind and CCUS projects were identified during the workshops held to assess the potential risks for overlap.

The following table details the opportunities that were identified in the workshops:

	Opportunity Description						Assessment									
ID	Opportunity	Cause	Consequence	Offshore Wind Project Phase	CCUS Project Phase	Notes / Context	Probability	Personnel Impact (P)	Environment Impact (E)	Asset Impact (A)	Reputation Impact (R)	Schedule Impact (H)	Social Impact (S)	Financial Impact (F)	Assessment	Assessment
O001	Opportunity to: Share survey data	Due to: Same area being surveyed and same information required	Resulting in: Reduced project development costs and schedule plus reduced operating costs	Development	Exploration & appraisal Development	No further notes	5	0	0	0	2	3	2	4	20	High
O002	Opportunity to: Share vessels and helicopters for construction, operation and decommissioning	Due to: Potential alignment of activities and similar vessel requirements	Resulting in: Reduced costs for CCUS and Offshore Wind developers / operators	Development Installation & commissioning Operations & maintenance Decommissioning	Exploration & appraisal Development Operations & maintenance Decommissioning Post-decom	No further notes	4	0	0	0	2	3	2	4	16	High
O003	Opportunity to: Share emergency response resources	Due to: Same are being utilised and similar emergency response requirements	Resulting in: Reduced costs for CCUS and Offshore Wind developers / operators plus potential reduced personnel risks	Installation & commissioning Operations & maintenance Decommissioning	Development Operations & maintenance Decommissioning	No further notes	4	4	0	0	2	0	3	4	16	High

	Opportunity Description						Assessment										
ID	Opportunity	Cause	Consequence	Offshore Wind Project Phase	CCUS Project Phase	Notes / Context	Probability	Personnel Impact (P)	Environment Impact (E)	Asset Impact (A)	Reputation Impact (R)	Schedule Impact (H)	Social Impact (S)	Financial Impact (F)	Assessment	Assessment
O004	Opportunity to: Improve project execution and operational safety	Due to: Existing Oil and Gas industry knowledge / lessons learned across a wide range of risk areas	Resulting in: Reduced project development costs and schedule plus reduced operating costs plus improved personnel safety and environmental performance	Installation & commissioning Operations & maintenance Decommissioning	Development Operations & maintenance Decommissioning	Particularly applicable in areas such as crossing of infrastructure, simultaneous operations, dropped objects, etc.	4	4	0	4	4	3	3	4	16	High
O005	Opportunity to: Share / re-use infrastructure	Due to: Similar requirements for many elements of projects (e.g. power cable to shore, communications, etc.)	Resulting in: Reduced costs for CCUS and Offshore Wind developers / operators	Installation & commissioning Operations & maintenance Decommissioning	Development Operations & maintenance Decommissioning Post-decom	Query - who retains responsibility for decommissioning shared / re-used infrastructure?	3	0	0	0	2	0	2	5	15	High
O006	Opportunity to: Develop CCUS monitoring to minimise issues with Offshore Wind co-location	Due to: Potential technology developments (e.g. on bottom node seismic, seabed gravity monitoring, etc.), relaxation of regulatory 4D seismic requirements, etc.	Resulting in: Reduced costs for CCUS and Offshore Wind developers / operators	Operations & maintenance	Exploration & appraisal Development Post-decom	No further notes	3	0	0	0	4	0	4	5	15	High
O007	Opportunity to: Pro-actively plan for co-location of CCUS and Offshore Wind developments	Due to: Clear understanding of the potential locations and requirements for CCUS and Offshore Wind and how they may interact	Resulting in: Minimisation of co-location risks	Development	Exploration & appraisal Development	No further notes	3	0	0	0	4	3	4	5	15	High

	Opportunity Description						Assessment									
ID	Opportunity	Cause	Consequence	Offshore Wind Project Phase	CCUS Project Phase	Notes / Context	Probability	Personnel Impact (P)	Environment Impact (E)	Asset Impact (A)	Reputation Impact (R)	Schedule Impact (H)	Social Impact (S)	Financial Impact (F)	Assessment	Assessment
O008	Opportunity to: Utilise Offshore Wind infrastructure to support CCUS	Due to: Power availability in-field, foundation / grid structure for on bottom node seismic monitoring, potential UAV / USV docking and charging stations	Resulting in: Reduced costs for CCUS and Offshore Wind developers / operators	Operations & maintenance	Operations & maintenance Post-decom	No further notes	3	0	0	0	2	0	2	4	12	Medium
O009	Opportunity to: Align standards across CCUS and Offshore Wind	Due to: Similar requirements for many elements of projects	Resulting in: Increased potential to share and re-use infrastructure plus cross-industry personnel experience / availability	Development	Exploration & appraisal Development	No further notes	4	0	0	0	3	0	2	3	12	Medium
O010	Opportunity to: Extend the life of part of an Offshore Wind development	Due to: Need to power co-located CCUS development	Resulting in: Reduced costs for CCUS and Offshore Wind developers / operators	Operations & maintenance	Operations & maintenance	Note that power requirements for CCUS would typically be quite low, apart from: - Early phase injection in depleted hydrocarbon reservoirs (potential for offshore heating requirements in the order of 10 mega-watts) Power would need to be "steady" but could be supplemented by on-site power generation	3	0	0	0	2	0	3	4	12	Medium

	Opportunity Description						Assessment									
ID	Opportunity	Cause	Consequence	Offshore Wind Project Phase	CCUS Project Phase	Notes / Context	Probability	Personnel Impact (P)	Environment Impact (E)	Asset Impact (A)	Reputation Impact (R)	Schedule Impact (H)	Social Impact (S)	Financial Impact (F)	Assessment	Assessment
O011	Opportunity to: Develop Offshore Wind in new areas	Due to: CCUS site closure making available seabed area that had previously been excluded for Offshore Wind	Resulting in: New Offshore Wind seabed area being available	Development	Post-decom	No further notes	4	0	0	0	2	0	3	3	12	Medium
O012	Opportunity to: Utilise CCUS infrastructure to support Offshore Wind	Due to: CCUS infrastructure being in place allowing pre-development monitoring of potential Offshore Wind sites (e.g. met mast)	Resulting in: Reduced costs for CCUS and Offshore Wind developers / operators	Development	Operations & maintenance	No further notes	3	0	0	0	2	0	2	3	9	Medium

Table 7.1: Potential Opportunities to Improve Delivery and Performance of Overlapping Offshore Wind and CCUS Projects

As can be seen from the above table, the opportunities identified during the workshops are broadly in line with the potential future mitigations for managing the risks in section 6.

8 Impact of Different Project Development Types and Proximity

8.1 Introduction

The following sections assess the impact that different Offshore Wind project types (e.g. fixed versus floating wind turbines) and CCUS (e.g. saline aquifer versus depleted hydrocarbon store) have on the identified underlying sources of risks and the associated mitigations identified in this study.

In terms of overlap, the area of interest is the seabed footprint of an Offshore Wind farm versus the projected seabed area above the extents of a CCUS store (i.e. not limited to the surface infrastructure of a CCUS project, which will tend to be relatively small).

In addition, the following sections also assess what impact the level of overlap (i.e. in close proximity with no overlap, partial overlap and extensive overlap) have on those risks and mitigations.

8.2 Lack of Clarity of Business Overlap Issues

The main area of concern for this source of risk is how commercial issues associated with overlapping of Offshore Wind and CCUS projects such as development planning / precedence, promotion of collaboration, alignment of standards, cross-industry liabilities and dispute mediation would be handled.

The impact of differing types of Offshore Wind or CCUS projects is not considered to have a significant impact on the risks or mitigations associated with this source of potential risk.

Similarly, Offshore Wind and CCUS projects with any degree of physical overlap are likely to experience the same levels of risk with the identified mitigations for those risks being equally as effective for those projects.

There would likely be a reduction in risk for projects where a CCUS storage complex (i.e. the extent of the subsurface store) and an Offshore Wind project are not physically overlapping but are located near each other. However, it is not considered that this would be significant with respect to the overall conclusions of this study.

8.3 Interaction with CCUS MMV Surveys

8.3.1 Offshore Wind Project Types

The main area of concern for this source of risk is the potential incompatibility between elements of CCUS MMV schemes (in particular, the requirements for seismic surveys and especially towed streamer seismic surveys) and the presence of Offshore Wind infrastructure.

The main difference considered for Offshore Wind projects is fixed versus floating substructures for wind turbines.

Considering the physical access requirements for "surface" seismic surveys (either towed streamer or on-bottom node surveys), the potential for any snagging of seismic survey equipment on turbine substructures or mooring lines is the key area of risk. As discussed in section 4.1.1, the spacing between the wind turbines is predominantly driven by the diameter of the individual wind turbine rotors and not by the type of substructure or mooring lines.

The typical spacing between wind turbines is less than would be required for towed streamer type seismic surveys (which is the current "normal practice" for seismic surveys) due to the width and length requirements for the sensor array towed behind the vessel, resulting in a high risk of snagging of the sensor array. This does not change with differing substructures for wind turbines.

In comparison, on-bottom node seismic surveys only require a seismic source (typically an airgun) to be towed behind the survey vessel with the sensors for the survey distributed on the seabed. This means that this type of survey could potentially be suitable for use in an area that overlaps existing Offshore Wind infrastructure. It is noted that, while this is likely the case, there is greater potential for snagging of the seismic source on the mooring lines associated with floating wind turbine substructures than for fixed substructures, although this is not considered to be a significant risk. It is noted that on-bottom node seismic surveys may not deliver the same level of data quality and are currently higher cost than towed streamer surveys.

The other factor to be considered for this source of risk with overlap projects is the potential for Offshore Wind infrastructure to degrade the quality of results from seismic surveys through ambient noise or signal interaction with subsurface support structures (e.g. turbine foundations).

The potential levels of ambient noise for fixed versus floating wind turbine substructures are considered to be broadly similar but there is a higher potential for signal interaction with the foundations of a fixed wind turbine substructure as the turbine foundations for static sites are larger (in diameter and depth) than anchors used to secure the mooring facilities for a floating substructure.

8.3.2 CCUS Project Types

For this common element, the only difference in CCUS project type that is relevant is the type of store; saline aquifer or depleted hydrocarbon reservoir. This is most applicable during the characterisation stage for a CCUS store as it is likely that sufficient data already exists for a depleted hydrocarbon reservoir to remove any requirement to perform seismic surveys to "prove the store" prior to project development.

However, this is not the case during the development, operations / maintenance, decommissioning or post-decommissioning stages of a CCUS project's lifecycle, where it is unlikely that the type of store would impact on whether there is a requirements for seismic surveys as part of the MMV scheme.

8.3.3 Degree of Overlap

As with the majority of the other common elements, partial or complete overlap of Offshore Wind and CCUS projects makes relatively little difference to the issue of interaction between CCUS MMV schemes and Offshore Wind infrastructure.

However, for projects that are in close proximity without physical overlap, there is potential to define a "minimum separation distance" between an Offshore Wind project and a CCUS store to ensure that the Offshore Wind project has no impact on the CCUS MMV requirements.

This separation distance would be driven by two areas:

- How much separation distance would be required to enable towed streamer (or on-bottom node) seismic surveys to be carried out without a risk of snagging on Offshore Wind infrastructure?
- What separation distance is required to ensure that there is no degradation of survey quality from Offshore Wind infrastructure?

It was not within the scope of this study to determine this separation distance, but it is recommended that consideration be given to further study in this area to determine the potential allowable minimum separation distance.

8.4 Increased Site Operations

The main area of concern for this source of risk is the increase in site operations that would result from overlapping Offshore Wind and CCUS projects and the impact of this increase on personnel safety, environmental performance and supply chain availability.

The impact of differing types of Offshore Wind or CCUS projects is not considered to have a significant impact on the risks or mitigations associated with this source of potential risk.

There would likely be a reduction in risk with lessening degrees of overlap between Offshore Wind and CCUS projects. However, it is not considered that this would be significant with respect to the overall conclusions of this study.

8.5 Physical Impacts / Damage

8.5.1 Offshore Wind Project Types

The main area of concern for this source of risk is the potential for ongoing Offshore Wind or CCUS project activities to cause physical damage to an overlapping project's infrastructure.

Differing foundation types (floating or fixed configurations) have varying levels of criticality from physical damage or impact, e.g. jacket structures inherently incorporate a degree of redundancy against damage to its members, compared with monopiles or floating substructures that may have primary structural elements with no redundancy. However, the impact of differing types of Offshore Wind projects is not considered to have a significant impact on the risks or mitigations associated with this source of potential risk.

8.5.2 CCUS Project Types

The only areas where a different CCUS project type could impact the scope and scale of this source of risk are the following:

- The potential for a leak of CO_2 from a CCUS store to cause personnel risk to ongoing Offshore Wind operations.
- The potential for brine release from a CCUS store to cause corrosion damage to Offshore Wind infrastructure.

As described in section 4.2.2, a depleted hydrocarbon reservoir will tend to have a higher level of intrinsic risk associated with potential leaks from wells that were previously drilled into the reservoir and may not have been abandoned in a way that is ideal for a CCUS store. It is noted that this is an incremental increase in the risk of a leak happening and that the CCUS project would be obligated to show how this risk would be managed, whether it overlaps an Offshore Wind project or not. It is also noted that the probability of a catastrophic leak from an existing well is considered to be very low. In light of the above, it is unlikely that any additional measures need to be taken to manage this risk for an overlapping CCUS project.

The potential for brine release affecting Offshore Wind infrastructure is only applicable to saline aquifers, and in the majority of cases, will not be an issue, assuming that it is considered that the majority of offshore CCUS projects will target saline aquifers where the installation of brine release wells is not required. Brine release wells have been installed on onshore CCUS projects to date but that has mainly been due to the size and capacity of saline aquifers local to the captured CO_2 source not being sufficient to cater for the required injection rate.

As offshore CCUS stores will, by their nature, be remote from the captured CO_2 source, this is not as large a consideration as for onshore CCUS projects and there will be more freedom to select a CCUS store that has the size and capacity that is suitable for the project CO_2 injection rates.

However, there is potential for brine release wells to be required following commencement of injection if the CCUS store does not perform as anticipated and, as such, it is recommended that the potential for saline brine causing corrosion damage to Offshore Wind infrastructure is studied further so that any mitigating measures such as separation distances between wells and wind turbine substructures can be quantified and put into practice.

8.5.3 Degree of Overlap

There would likely be a reduction in risk from this source with lessening degrees of overlap between Offshore Wind and CCUS projects.

8.6 Existing Infrastructure Blocking Access

The main area of concern for this source is the potential impact that any existing infrastructure from an Offshore Wind or CCUS project would have on the development planning of a new, overlapping project.

The impact of differing types of Offshore Wind or CCUS projects is not considered to have a significant impact on the risks or mitigations associated with this source of potential risk. It is noted that floating Offshore Wind substructures may have a larger sea area footprint that fixed substructures but this is not considered to be a significant issue as the typical spacing between turbines means that the differences in sea area footprint are relatively minor.

There would likely be a reduction in risk with lessening degrees of overlap between Offshore Wind and CCUS projects. However, it is not considered that this would be significant with respect to the overall conclusions of this study.

9 Conclusions and Recommendations

At a high level, the study concluded that the co-location of CCUS and Offshore Wind projects is potentially feasible with appropriate mitigations but a range of challenges due to co-location were identified.

9.1 Common Elements

By gathering input from a range of organisations through interactive workshops, this study identified a total of 46 unique risks associated with developing overlapping projects; 16 of which were classified as having a high impact, 26 having a medium impact and 4 having a low impact.

The following common elements result in the majority (all but 2 of the medium impact risks) of the identified risk items across all project lifecycle. As a result, these can be considered to be the main sources of potential risk for overlapping of Offshore Wind and CCUS projects:

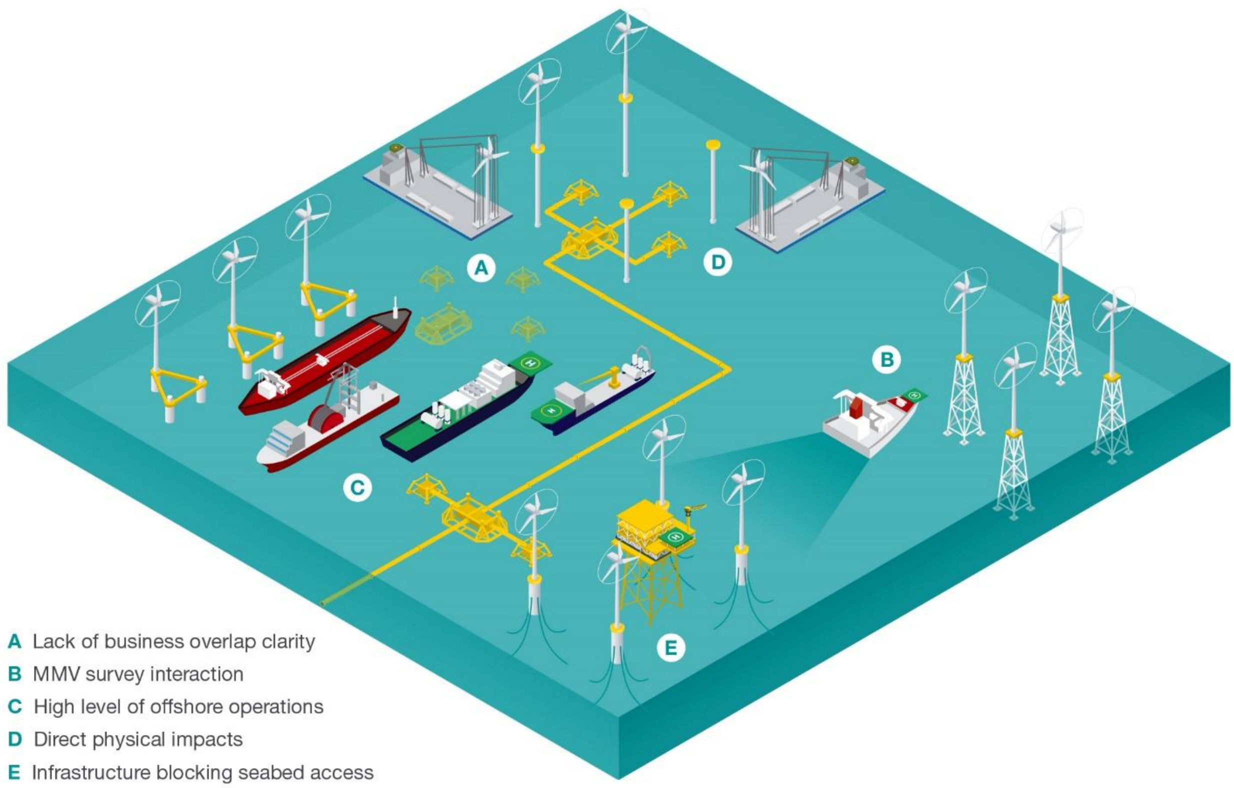

Figure 9.1: Common Elements of Risks for Overlapping Offshore Wind and CCUS Projects

A. A lack of clarity over how issues associated with overlapping of Offshore Wind and CCUS projects in terms of development planning / precedence, promotion of collaboration, alignment of standards, cross-industry liabilities and dispute mediation would be handled.

B. The requirement to perform MMV surveys (particularly seismic surveys) for CCUS projects across their lifecycle and the interaction with Offshore Wind infrastructure.

C. A higher level of offshore operations that result from locating two projects in the same area.

D. Direct physical impacts to infrastructure or personnel due to incidents occurring as a result of overlapping projects.

E. The physical infrastructure of a pre-existing project blocking access to the seabed or modifying the requirements for new projects.

9.2 Potential Mitigation Measures

A range of potential mitigation measures for reducing the impact of the identified risks (including those not covered by common elements A to E) were assessed, which were classified into the following categories:

- Good practice mitigation measures: Mitigation measures that can be applied now without further study or development based upon good practice across the Offshore Wind and CCUS industries.
- Future mitigation measures: Mitigation measures that could potentially be applied in future but require some further technology development or further study work to determine whether they are feasible and economic.

The overall impacts of the identified risks across the individual lifecycles of overlapping Offshore Wind and CCUS projects plus the impact of the identified mitigation measures are illustrated in the following figure (red = high concentration of risks and impacts, amber = medium concentration of risks and impacts, green = low concentration of risks and impacts):

Figure 9.2: Offshore Wind and CCUS Project Lifecycle Risk Levels

9.2.1 Good Practice Mitigations

The identified current good practice measures are dependent on good co-ordination and communication between overlapping project developers and across both industries in a wider sense plus applying lessons learned from the upstream oil and gas industry to mitigate against any detrimental impact of overlapping project site activities. These measures mainly impact common elements C to E, which are mainly associated with ensuring that overlapping projects consider each other's needs and activities.

9.2.2 Potential Future Mitigations

The following potential future mitigations apply across a number of the common elements for risks for overlapping Offshore Wind and CCUS projects:

- Consider appointing a common oversight body for overlapping Offshore Wind and CCUS projects, consisting of a combination of government and industry bodies, to provide input to enable issues such as overlap planning opportunities, development planning / precedence, promotion of collaboration, alignment of standards, cross-industry liabilities and dispute mediation to be handled..

- Pro-actively review where Offshore Wind and CCUS projects could potentially overlap (i.e. where are the good CCUS stores versus the high potential Offshore Wind sites) and ensure a combined approach to planning in those areas.

The application of the above future mitigations has the potential to significantly reduce the overall impact across the majority of the identified risks.

9.3 CCUS MMV (Seismic Surveys)

Even assuming that initial CCUS site investigation can be carried out before the start of development operations of a co-located Offshore Wind site, a critical risk is presented by the interaction of seismic surveys required for CCUS MMV operations with Offshore Wind infrastructure. The main recommendations for areas of immediate future work to resolve this major risk area include:

- Pro-actively review where Offshore Wind and CCUS projects could potentially overlap and consider performing site characterisation activities in these areas prior to any Offshore Wind or CCUS project development.
- Clearly define the best practice and minimum acceptable practice in terms of CCUS MMV schemes, through the regulator performing a review of current MMV requirements to minimise the need for seismic surveys in particular, and ensure that these are taken into account when planning overlapping CCUS and Offshore Wind projects on a case-by-case basis.
- Provide government/regulator support for a future technology development campaign in reservoir characterisation and MMV to remove the dependency on new seismic acquisition (e.g. forward modelling of response of different reservoir types' rock physics response to CO_2 flood; what constitutes appropriate monitoring post-injection).

While differing types of Offshore Wind (e.g. fixed versus floating wind turbine sub-structures) and CCUS (saline aquifer store versus depleted hydrocarbon store) and levels of overlap/proximity do incrementally affect the risks identified in this study, they do not change the above overall conclusions for good practice mitigations or recommendations for areas of future development in managing those risks.

9.4 Recommended Action

There are two specific areas of study where it is recommended that action is taken now to further understand the risks associated with Offshore Wind and CCUS projects being developed in close proximity:

- Conduct further study in to determine the potential allowable minimum separation distance between a CCUS storage complex and an Offshore Wind site to
  - Minimise degradation of seismic survey results from Offshore Wind ambient noise or foundation signal reflection issues.

    - Examine the challenges presented by limiting access for wells and relief wells, including their exclusion zones for vessel and helicopter access.
    - Enable safe and efficient rig helicopter operations support (Crew Change, Emergency Medivac, Search and Rescue) within the wind farm.
    - Minimise impact to reduction of conventional weather window for rig mobilisation within wind farms.
- Assess the level of risk of corrosion damage to offshore wind infrastructure caused by saline brine displacement from CO_2 injection into saline aquifers at depth so that any mitigating measures such as separation distances between brine release wells and wind turbine substructures can be quantified and put into practice.

There is significant benefit and value in investing now to develop the potential future mitigation measures identified in this study to reduce the overall risk presented by overlapping Offshore Wind and CCUS projects.

It is highly recommended that an over-arching committee (e.g. formed from one or more of The Crown Estate, Crown Estate Scotland, the OGA and an Offshore Wind representative body) takes ownership and coordinates the implementation of the areas for further work identified in this study to ensure that the risks and opportunities associated with co-locating Offshore Wind and CCUS projects are fully understood and appropriate mitigation measures are explored in detail ahead of the future development of such projects.

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Appendix 1 Risk and Opportunity Assessment Matrices

Risk Assessment Matrix:

CONSEQUENCE								LIKELIHOOD				
								Very Unlikely	Unlikely	Possible	Likely	Very Likely
Personnel P	Environment E	Asset A	Reputation R	Schedule H	Social S	Financial F	Severity	A freak combination of factors would be required for an incident to occur 1	A rare combination of factors would be required for an incident to occur 2	Could happen when additional, unusual factors are present but otherwise unlikely to occur 3	Not certain to happen under normal conditions but could happen if a predictable additional factor was present 4	Almost inevitable that an incident would result 5
Multiple fatalities	Severe release of CO_2 / regulatory enforcement	Extensive damage - major interruption to operations	Serious international reputation impact Revocation of permit or corporate prosecution	>10% of Overall Project Appraisal, Development and Implementation Schedule	Sustained international press coverage Long term major negative impact on local workforce Long term interruption to business from social pressure	Business value change: > 20% project total technical cost increase	**5**	**Medium / Alert**	**Medium**	**High**	**High**	**Very High**
Single fatality or total permanent disability	Major release: ≥ 20 and <50 CO_2 or non-PLONOR chemical	Major damage - short term interruption to operations or permanent reduction in capacity by >50%	Major National reputation impact Prohibition notice	6-10% of Overall Project Appraisal, Development and Implementation Schedule	International press coverage Medium term major negative impact on local workforce Medium term interruption to business from social pressure	Business value change: 10-20% project total technical cost increase	**4**	**Low / Caution**	**Medium**	**Medium**	**High**	**High**
Major Injury Includes injuries requiring >7 consecutive days off work as per RIDDOR definition	Serious release ≥1 and <20 tonnes CO_2 or non-PLONOR chemical	Moderate damage - shut down of major part of installation but not all or permanent reduction in capacity between 25 - 50%	Local reputation impact Improvement notice or enforcement notice	2-6% of Overall Project Appraisal, Development and Implementation Schedule	National press coverage Medium term minor negative impact on local workforce Short term interruption to business from social pressure	Business value change: 5-10% project total technical cost increase	**3**	**Low**	**Low**	**Medium**	**Medium**	**High**
Moderate injury Includes injuries requiring 3 or more consecutive days off work and recordable under RIDDOR	Minor release: <1 tonne CO_2 or non-PLONOR chemical >10 tonnes of a PLONOR chemical	Minor damage - shut down of small part of installation or permanent reduction in capacity < 25%	Internal reputation impact Informal notification of opportunities for improvement or letter	1-2% of Overall Project Appraisal, Development and Implementation Schedule	Local press coverage Short term major negative impact on local workforce	Business value change: <5% project total technical cost increase	**2**	**Very Low / Caution**	**Low**	**Low**	**Medium**	**Medium**
Minor Injury Injuries requiring <3 days off work, or no time off. Not recordable or reportable under RIDDOR	Negligible release: Release of 10 tonnes or less of a PLONOR chemical. None or minimal clean-up required. PLONOR: Considered to pose little or no risk to the environment	Slight damage - no shut down required with temporary impairment of capacity	Scrutiny from internal auditor - ICP action	<1% of Overall Project Appraisal, Development and Implementation Schedule	Internal corporate coverage Short term minor negative impact on local workforce	Business value change: Negligible project total technical cost increase	**1**	**Very Low**	**Very Low**	**Low**	**Low**	**Medium**
No Injury	No release or environmental impact	No damage	No impact	No impact	No impact	No cost	**0**	**Very Low**				

Opportunity Assessment Matrix:

CONSEQUENCE								LIKELIHOOD				
								Very Unlikely	Unlikely	Possible	Likely	Very Likely
								A freak combination of factors would be required for the opportunity to be realised	A rare combination of factors would be required for the opportunity realised	Could happen when additional effort put in but otherwise unlikely to occur	Not certain to happen under normal condiitons but could happen without significant effort	Almost inevitable that the opportunity would be realised
Personnel P	Environment E	Asset A	Reputation R	Schedule H	Social S	Financial F	Severity	1	2	3	4	5
Saves Multiple Lives	Transformational Environmental Improvement	Prevents extensive damage - extended complete interruption to operations	International Improvement	Saves >10% of Overall Project Appraisal, Development and Implementation Schedule	Positive sustained international press coverage Long term major local employer	Business value change: > 20% project total technical cost decrease	**5**	**Medium / Alert**	**Medium**	**High**	**High**	**Very High**
Saves a Life	Major Footprint Improvement	Prevents major damage - short term complete interruption to operations	National Improvement	Saves 6-10% of Overall Project Appraisal, Development and Implementation Schedule	Positive international press coverage Medium term major local employer	Business value change: 10-20% project total technical cost decrease	**4**	**Low**	**Medium**	**Medium**	**High**	**High**
Significant Health and Safety Improvement	Significant Footprint Improvement	Prevents moderate damage - short term shut down of major part of installation	Significant Improvement	Saves 2-6% of Overall Project Appraisal, Development and Implementation Schedule	Positive national press coverage Medium term minor local employer	Business value change: 5-10% project total technical cost decrease	**3**	**Low**	**Low**	**Medium**	**Medium**	**High**
Limited Health and Safety Improvement	Limited Footprint Improvement	Prevents minor damage - short term shut down of small part of installation	Limited Improvement	Saves 1-2% of Overall Project Appraisal, Development and Implementation Schedule	Positive local press coverage Short term major local employer	Business value change: <5% project total technical cost decrease	**2**	**Very Low**	**Very Low**	**Low**	**Medium**	**Medium**
Slight Health and Safety Improvement	Slight Footprint Improvement	Prevents slight damage - temporary impairment of capacity	Slight Improvement	Saves <1% of Schedule	Positive internal corporate coverage Short term medium local employer	Business value change: Negligible project total technical cost decrease	**1**	**Very Low**	**Very Low**	**Low**	**Low**	**Medium**
No personnel benefit	No environmental benefit	No asset benefit	No reputational benefit	No schedule improvement	No social impact improvement	No value benefit	**0**	**Very Low**				

Appendix 2 CCUS MMV Technology Status

Name	Description	Monitored Zone	Equipment	Pre / Post Processing requirements	Risk Category	Advantages	Limitations	TRL	Suitable for Subsea CCUS	Exploration & Appraisal	Development	Operations & Maintenance	Decommissioning / Post-decommissioning
2D surface seismic	2D linear image for site characterization and time-lapse monitoring to survey potential changes due to CO2 injection	Surface/Near-Surface/Reservoir	Seismic sensors, source arrays, and sources	Baseline surveys, geocharacteristion, and multiple data processing events	Capacity, containment, contingency, mitigation	Site characterization prior to injection and time-lapse monitoring to survey potential changes due to CO2 injection. Identification of potential fractures and faults in the subsurface.	small scale faults with offsets >10 metres are not detectable, lacks full surface coverage	5	Y	Y	Y	Y	Y
3D surface seismic	3D data on storage and reservoir characterization and time-lapse monitoring to survey CO2 distribution and mitigation	Surface/Near-Surface/Reservoir	Seismic sensors, source arrays, and sources	Baseline surveys, geocharacteristion, and multiple data processing events	Capacity, containment, contingency, mitigation	Full site characterization of overburden and storage zones. Monitor CO2 migration in the well Identification of potential fractures and faults in the subsurface.	small scale faults with offsets >10 metres are not detectable, requires extensive data processing	5	Y	Y	Y	Y	Y
Annulus Pressure testing	Tests designed to pressure annulus space and measure pressure drop to ensure well integrity and prevent casing leaks	Near-Surface/Reservoir: Wellbore system	Pressure gauge on wellhead	Simple test	Contingency, Mitigation	Direct test, low-cost	Limited to well system, not continuous test	8	Y	N	N	Y	N
Boomer/Sparker profiling	2D sub-bottom water profiling used for site characterization and to detect changes due to injected CO2	Surface/Near-Surface/Reservoir	Vessel, source/hydrophone array, ship explosives, vessel and crew	Baseline, post injection, processing & interpretation of difference	Capacity, containment, contingency, mitigation	Provides continuous mapping of shallow sediment layers, structural changes due to CO2 migration and leakage, high peak frequencies and large bandwidth for higher resolution	Limited tow capability, high voltage/high current, boomer plates are large and constrain towing	7	Y	N	Y	Y	Y
Borehole EM	Images changes in electrical resistivity signal from induction source and receiver array due to saturation changes between wells or shallow soil zone	Surface/Near-Surface/Reservoir	At least two wells with string array of electrodes attached to well casing	Baseline, post injection, processing & interpretation of difference	Capacity, Containment	Focused on reservoir zone, more accurate than some other seismic methods, lower processing	Only covers interwell cross section zone, subject to interpretation, requires high CO2 saturation, non-conductive pipe	5	Y	N	N	Y	N
Bubble stream chemistry	Measures dissolved gases and chemistry of water to detect potential CO2	Surface/Near-Surface: Ground water and seafloor	Vessel or team of sampling units, samples, laboratory testing	Baseline and continuous sampling	Containment, contingency, mitigation	Provides dissolved gas and other chemistry of specific zones of interest. Can determine minor and major leakage.	Frequent sampling is needed to monitor containment of CO2. Does not measure over an entire area so several samples from different locations are necessary for analysis.	8	Y	N	N	Y	Y
Bubble stream detection	High frequencies used to measure seafloor and create acoustic images of seafloor to determined potential pits created by CO2 leakage	Surface: Seafloor	Vessel, echosounders, processing	Baseline, post injection, processing & interpretation of difference	Containment, contingency, mitigation	Detailed high images created of seafloor which can detect deformation changes and density changes due to CO2	Extensive seafloor mapping required in order to example baseline and repeat data. Minor leaks can go undetected due to resolution of technology	7	Y	N	Y	Y	Y
Casing Inspection logs	Downhole survey of well materials for indication of defects	Surface/Near-Surface/Reservoir: Wellbore system	Calliper, flux, sonic, EM, or noise logging tool	Processing and Interpretation of results	Containment	Straight forward test, can show precursors of corrosion, failure	Periodic test, well must be shut-in, interrupts operations	8	Y	N	N	Y	N
Casing pressure monitoring	Monitoring pressure on casing annulus for casing leaks	Surface/Near-Surface/Reservoir: Wellbore system	Annulus pressure system and pressure gauge	Direct monitoring	Containment	Direct test, low-cost, often regulatory requirement	Limited to well system, does not provide location of defect	8	Y	N	N	Y	N
Cement bond logging	Acoustic log that provides evaluation of cement/casing to measure well integrity and zone isolation	Surface/Near-Surface/Reservoir: Wellbore system	Wireline vendor and service rig	Baseline, post injection, processing	Containment	Simple quantitative method for analysing cement quality and inferring compressive strength	Limited to only evaluating cement bonding to the casing. Does not provide imaging between cement and formation. Does not evaluate low density cement.	8	Y	N	Y	N	Y
Corrosion Monitoring (well materials)	Inspection and/or corrosion tickets in wells to detect any corrosion of well materials	Surface/Near-Surface/Reservoir: Wellbore system	Coupons, mechanical, ultrasonic, and electromagnetic tools	Interpretation of results	Containment	Straight forward test, can show precursors of corrosion, failure	Periodic test, well must be shut-in, interrupts operations	8	Y	N	N	Y	N
Crosswell Seismic	Inter-well seismic profiling to measure structural changes due to CO2 injection	Surface/Near-Surface/Reservoir: Between wellbores	Wireline vendor, service rig, source and receiver arrays	Baseline survey, processing of periodic surveys to show difference	Capacity, containment, contingency, mitigation	Subsurface monitoring of injection of CO2 plumes. Estimate rock and fluid properties. Identification of potential fractures and faults in the subsurface.	Source strength is limited by the distance between wellbores. Presence of gas in the well can reduce detection of CO2. Geologic complexity and noise interferences can degrade seismic data. The maximum distance between wells is dependent on casing.	5	Y	N	N	N	N

Name	Description	Monitored Zone	Equipment	Pre / Post Processing requirements	Risk Category	Advantages	Limitations	TRL	Suitable for Subsea CCUS	Exploration & Appraisal	Development	Operations & Maintenance	Decommissioning / Post-decommissioning
Distributed Acoustic Sensing	Laser light pulses from permanent downhole fibre optic cables seismic profiling that measures reservoir and caprocks to determine structural changes due to CO_2 injection and reservoir integrity	Surface/Near-Surface/Reservoir: Proximal to wellbore	Vendor, fiber optics, permeant onsite data acquisition	Continuous	Capacity, Containment, Mitigation	Provides continuous monitoring of the well site and can be used to detect changes due to CO_2 injection	A large amount of data is produced from this technology and requires extensive and costly processing. Can cause integrity issues if not installed correctly	5	Y	N	N	Y	N
Distributed Temperature Sensing	Linear fibre optic cables that measures changes in temperature to detect/monitor temperature indicators of CO_2	Surface/Near-Surface/Reservoir: Proximal to wellbore	Vendor, fiber optics, permeant onsite data acquisition	Continuous	Containment, Mitigation	Provides continuous temperature monitoring and migration CO_2	A large amount of data is produced from this technology and requires extensive and costly processing. Can cause integrity issues if not installed correctly	5	Y	N	N	Y	N
Downhole fluid chemistry	Provides fluid chemistry from reservoir zones to determine CO_2 migrations and analyse reservoir conditions	Reservoir	Wireline/slickline vendor with bailer, laboratory services	Baseline and regular repeat sampling, laboratory testing	Capacity, Containment, Mitigation	Formation fluids can be collected directly from the zone of interest	Fluid sampling in high risk wells is a potential hazard, fluid around sampler may be in two-phase condition, mechanical failure of sampler due to pressures and fluid present	8	Y	N	N	Y	N
Downhole pressure/temperature	Continuous temperature and pressure measurements to monitor reservoir integrity and CO_2 migration	Reservoir	Wireline/slickline vendor with bailer, laboratory services	Direct monitoring	Injectivity, containment, contingency, mitigation	Continuous in-place monitoring, batteries can potentially last up to a year	Gaskets can corrode over time and cause gauge malfunctioning,	8	Y	N	N	Y	N
Ecosystems studies	Survey of flora and fauna for stress or damage caused by CO_2 leakage	Atmospheric/Surface: Soil, atmosphere	Visual survey, inspection, flyover of CO_2 storage area	Baseline survey, regular repeat surveys	Contingency, mitigation, public acceptance	Low impact technology, non-invasive, simple	Requires significant CO_2 migration to detect leakage, not suitable for areas without vegetation, qualitative	7	Y	N	Y	Y	Y
Electric Spontaneous Potential	Measures mineral and clay compositions, and can show porosity mineralogical changes near wellbore which can be used to indicate potential wellbore integrity	Reservoir: Wellbore	Wireline vendor and service rig	Baseline, well schematics and geochemistry, post injection, processing & interpretation of difference	Capacity, Containment	Measures mineral and clay compositions, and can show porosity mineralogical changes near wellbore which can be used to indicate potential wellbore integrity	high clay and salinities are necessary for optimal functionality of the tool	5	Y	N	N	Y	N
Fluid geochemistry	Fluid measurements to determine rock-CO_2 interactions, monitor CO_2 migration and storage integrity/breach of CO_2	Reservoir: Wellbore	Wireline vendor and service rig	Baseline and regular repeat sampling, laboratory testing	Capacity, containment, contingency, mitigation	Formation fluids can be collected directly from the zone of interest or at the wellhead to analyse multiple zones of interest and	Fluid sampling in high risk wells is a potential hazard, fluid around sampler may be in two-phase condition, mechanical failure of sampler due to pressures and fluid present	8	Y	N	N	Y	N
Geophysical Density Logs	Measures wellbore densities to determine lithology and potential, changes and identifies CO_2 breakthrough and is used to analyse wellbore integrity	Surface/Near-Surface/Reservoir: Wellbore	Wireline vendor and service rig	Baseline survey	Capacity, Containment	Measures densities to determine lithology changes near wellbore which can be used to indicate potential wellbore integrity	susceptible to borehole rugosity/washouts and types of drilling muds. Erroneous lithology data due to averages between drastically different density lithology changes	5	Y	N	N	Y	N
Geophysical Pulse Neutron Capture logs	Measures wellbore fluid saturation (oil/gas/water), changes and identifies CO_2 breakthrough and is used to analyse wellbore integrity	Surface/Near-Surface/Reservoir: Wellbore	Wireline vendor and service rig	Baseline, well schematics and geochemistry, post injection, processing & interpretation of difference	Capacity, Containment	Fluid saturation of cased wells, porosity indicator, can show porosity changes near wellbore which can be used to indicate potential wellbore integrity	Fluid behind casing, cannot differentiate between various gases, high porosities and salinities are necessary for optimal functionality of the tool	5	Y	N	N	Y	N
Global Positioning System	Satellite technique that provides epochs with displacement measurements for ground deformation related to CO_2 storage	Surface/Near-Surface	Receiver, GPS antenna, power supply, pseudolites, pressure gauges, and satellite system	Baseline survey, periodic surveys	Containment, mitigation, public acceptance	Measures displacement in proximity or area of CO_2 reservoir	Temporal sampling may be limited, land use and access, atmospheric effects, satellite orbit coverage	7	Y	N	N	Y	Y

Name	Description	Monitored Zone	Equipment	Pre / Post Processing requirements	Risk Category	Advantages	Limitations	TRL	Suitable for Subsea CCUS	Exploration & Appraisal	Development	Operations & Maintenance	Decommissioning / Post-decommissioning
High resolution acoustic imaging	Acoustic full-waveform sonic to measures and images structural features and changes that occur due to CO2 injection	Reservoir: Wellbore	Wireline vendor and service rig	Baseline survey, regular repeat surveys	Containment, contingency, mitigation	Direct imaging and monitoring of borehole structures and changes due to CO2 injection	susceptible to borehole rugosity/washouts which will create poor quality images.	5	Y	N	N	Y	N
Long-term downhole pH	Optical sensors in casing that measures chemical changes due to CO2 changes	Surface/Near-Surface/Reservoir: Wellbore	Vendor, fiber optics, permeant onsite data acquisition	Continuous	Capacity, containment, contingency	Provides continuous pH monitoring and migration CO2, works in highly saline waters, good for high pressure and temperature environments	This is a near wellbore technology and provides data within specified installation zone.	5	Y	N	N	Y	N
Microseismic/Seismic Activity Monitoring	Passive technique for monitoring and identifying downhole fractures and microseismic events	Surface/Near-Surface/Reservoir: Reservoir and above	Borehole geophones, monitoring station, solar charge panels, strong motion-sensor	Baseline survey, analysis of data to estimate location of seismic event	Containment, Contingency	Can monitor fracture properties from downhole, surface to subsurface. Time-lapse monitoring to survey migration of CO2 plumes. Identification of potential fractures and faults in the subsurface.	Moderate changes in dip perturbation or velocity changes can cause errors in velocity models. Low and high frequency signals can affect mechanism inversion.	7	Y	N	Y	Y	N
Multibeam echo sounding	Sonar emitted by a vessel that measures distances and topography of the seafloor to determine surface changes due to CO2	Surface/Near-Surface/Reservoir: Seafloor	Vessel, sonic source, hydrophones, antenna	Baseline, post injection, processing & interpretation of difference	Containment, Contingency	Provides continuous mapping of shallow sediment layers, structural changes due to CO2 migration and leakage	Minor deformation is not detected due to resolution limitations.	7	Y	N	N	Y	Y
Multicomponent surface seismic	3D compressive and shear waves use to measure fluid changes and structural monitoring to survey CO2 distribution and migration	Surface/Near-Surface/Reservoir: Reservoir and above	Seismic sensors, source arrays, and sources (vibrator trucks/vibrator systems)	Baseline surveys, geocharacteristion, and multiple data processing events	Containment, Contingency	Full site characterization of overburden and storage zones. Monitor CO2 migration in the well Identification of potential fractures and faults in the subsurface.	small scale faults with offsets >10 m are not detectable, requires extensive data processing	7	Y	Y	Y	Y	Y
Operational Monitoring	CO2 injection flow rates, pressure, temperature, density, composition monitoring	Reservoir	Gauges and flowmeters	Direct measurements	Capacity, Injectivity	Monitor injection performance for pressure drops and flow variations	Limited to injection well	8	Y	N	N	Y	N
Produced Gas/Fluid Analysis	Gas/fluid sampling & analysis to determine CO2 interactions, monitor CO2 migration and storage integrity	Reservoir: Wellbore	Coriolis meter, laboratory testing	Baseline and regular repeat sampling, laboratory testing	Containment, contingency, mitigation	Formation samples can be collected directly from the zone of interest or at the wellhead to analyse multiple zones of interest	Fluid sampling in high risk wells is a potential hazard, fluid around sampler may be in two-phase condition, mechanical failure of sampler due to pressures and fluid present	8	Y	N	N	Y	N
Satellite interferometry/INSAR	Satellite-based technique that provides topographic images of site surface area to measure surface deformation	Surface/Near-Surface	Satellite, reflector stations	Baseline survey, multiple satellite passes for survey verification	Containment, contingency, public acceptance	Monitoring injection of CO2 in the subsurface at carbon sequestration test sites.	Level terrain, minimal land use, atmospheric effects, and satellite orbit coverage	5	Y	N	N	Y	Y
Seabottom EM	Images changes in electrical resistivity signal from induction source and receiver array measures surface changes due to CO2	Surface/Near-Surface	Vessel, source and several receiver strings	Baseline, post injection, processing & interpretation of difference	Containment, Contingency	Provides continuous mapping of seafloor structural changes due to CO2 migration and leakage, high peak frequencies and large bandwidth for higher resolution	Limited tow capability, high voltage/high current and constrain towing	7	Y	N	N	Y	Y
Seabottom gas sampling	Sampling at the sediment-seawater interface to measure density changes due to CO2	Surface/Near-Surface: Sediment/water Interval	Sampling units, samples, laboratory testing	Baseline and continuous sampling	Containment, contingency, mitigation, public acceptance	Provides dissolved gas and other chemistry of specific zones of interest. Can determine minor and major leakage.	Frequent sampling is needed to monitor containment of CO2. Does not measure over an entire area so several samples from different locations are necessary for analysis.	7	Y	N	N	Y	Y
Seawater chemistry	Measures temperature, pressure and chemistry of water to detect changes due to CO2	Surface/Near-Surface: Seafloor	Vessel or team of sampling units, samples, laboratory testing	Baseline and continuous sampling	Containment, contingency, mitigation	Provides dissolved gas and other chemistry of specific zones of interest. Can determine minor and major leakage.	Frequent sampling is needed to monitor containment of CO2. Does not measure over an entire area so several samples from different locations are necessary for analysis.	7	Y	N	N	Y	Y

Name	Description	Monitored Zone	Equipment	Pre / Post Processing requirements	Risk Category	Advantages	Limitations	TRL	Suitable for Subsea CCUS	Exploration & Appraisal	Development	Operations & Maintenance	Decommissioning / Post-decommissioning
Sidescan sonar	Sonar emitted from autonomous underwater vehicles that measure distances and topography of the seafloor to determine surface changes due to CO2	Surface/Near-Surface: Seafloor	Vessel, AUV, echosounders	Baseline, post injection, processing & interpretation of difference	Containment, Contingency	Provides continuous mapping of shallow sediment layers, structural changes due to CO2 migration and leakage, high peak frequencies and large bandwidth for higher resolution	Minor deformation is not detected due to resolution limitations.	7	Y	N	N	Y	Y
Single well EM	Images changes in electrical resistivity signal from induction source and receiver array due to CO2 saturation proximal well or shallow soil zone	Surface/Near-Surface/Reservoir: Reservoir or soil	One well with string array of electrodes attached to well casing	Baseline, post injection, processing & interpretation of difference	Capacity, containment, contingency	Focused on reservoir zone, more accurate than some other seismic methods, lower processing	Only covers interwell cross section zone, subject to interpretation, requires high CO2 saturation, non-conductive pipe	5	Y	N	N	Y	N
Surface gravimetry	Surface survey of gravimetric changes caused by CO2 storage	Reservoir	Gravity survey system or permanent gravity stations	Baseline, post injection, processing & interpretation of difference	Capacity, Containment	Low impact technology, non-invasive, can cover wide areas, high visibility	Low resolution, requires large volumes of CO2, subject to interpretation	8	Y	N	N	Y	Y
Tracers	Introduction of tracers into injection stream and monitoring in soil gas points for indications of leakage	Atmospheric/Surface: Soil, atmosphere	Soil gas monitoring points, gas collection equipment, analytical lab services	None	Containment, contingency, public acceptance	Direct measurements, simple technology, high visibility, easy to communicate	Requires careful sampling, false positives possible, requires significant CO2 migration to detect leakage	8	Y	N	N	Y	Y
Vertical seismic profiling (VSP)	Seismic profiling that images reservoir and caprocks to determine saturation changes due to CO2 injection	Surface/Near-Surface/Reservoir: Proximal to wellbore	Wireline vendor, service rig, source and receiver arrays	Baseline survey, processing of periodic surveys to show difference	Capacity, Containment	Site characterization prior to injection and time-lapse monitoring to survey migration of CO2 plumes. Identification of potential fractures and faults in the subsurface.	Presence of hydrocarbons or high salinity. Must verify that potential historical sites are not damaged during logging. 450 metre distance limitation.	5	Y	N	Y	Y	Y
Water bottom sediment sampling	Sampling at the seabed sediment for geochemical indicators of CO2	Surface/Near-Surface: Sediment/water Interval	Sampling units, samples, laboratory testing	Baseline and continuous sampling	Containment, contingency, mitigation	Provides dissolved gas and other chemistry of specific zones of interest. Can determine minor and major leakage.	Frequent sampling is needed to monitor containment of CO2. Does not measure over an entire area so several samples from different locations are necessary for analysis.	8	Y	N	N	Y	Y
Airborne EM	Air surveys to detect electrical conductivity variations in earth materials as indicator of CO2	Surface/Near-Surface: Soil, intermediate zones	Airplane, EM coil array	Baseline, post injection, processing & interpretation of difference	Contingency, mitigation, public acceptance	Covers large area, non-invasive	Limited depth penetration to 100s of metres, requires large CO2 storage plume	5	N	N	N	Y	Y
Airborne spectral imaging	Air surveys to detect spectral signal vegetative stress as indicator of CO2 leakage from the ground	Atmospheric/Surface: Soil, atmosphere	Airplane survey, hyperspectral imager	Baseline, post injection, processing & interpretation of difference	Contingency, mitigation, public acceptance	Covers large area, non-invasive	Natural CO2 variations, false positives	4	N	N	N	Y	Y
Borehole ERT	Images changes in electrical resistivity signal between 2 electrodes due to saturation changes between wells or shallow soil zone	Surface/Near-Surface/Reservoir	Electric source, downhole receiver array, at least 2 wells	Baseline, post injection, processing & interpretation of difference	Capacity, Containment	Focused on reservoir zone, more accurate than some other seismic methods, lower processing	Only covers interwell cross section zone, requires closely spaced wells, permanent installation, subject to interpretation, requires high CO2 saturation, non-conductive pipe	5	N	N	N	Y	N
Eddy covariance	Measurement of air flow and CO2 concentrations to detect CO2 leakage at the surface	Atmosphere	Stationary or mobile observation towers	Baseline, post injection, processing & interpretation of difference	Contingency, mitigation, public acceptance	Low impact technology, non-invasive, can cover wide areas, high visibility	Natural CO2 variations, false positives, sensitive to humidity, temperature	8	N	N	N	Y	Y
Ground penetrating radar	Geophysical method that processes reflection of high freq. radio waves to image features in the shallow subsurface	Surface/Near-Surface: Shallow soil and groundwater	GPR system (source/cart, data logger, software) and/or crosswell groundwater wells	Baseline survey, operational survey, post-injection, processing/interpretation of raw GPR results	Contingency, mitigation, public acceptance	Low impact technology, non-invasive	Requires significant CO2 migration to detect leakage, may be subject to interpretation bias, not suitable for low CO2 levels, limited to ~15 metres depth, certain sediments affect accuracy	8	N	N	N	Y	Y
Groundwater monitoring	Sampling and analysis of shallow groundwater wells for indicators of CO2 leakage and/or brine displacement	Surface/Near-Surface: Shallow groundwater quality	Shallow gw wells, sampling equipment, lab analysis	Baseline samples, interpretation of gw quality indicators,	Containment, contingency, mitigation, public acceptance	Direct monitoring of groundwater resources, high visibility monitoring, easy to communicate to stakeholders, understandable results	Relies on indicators of CO2 (pH, anions, cations, alk., TDS), false positives, needs good baseline data, may require significant CO2 migration to detect leakage	8	N	N	N	Y	Y

Name	Description	Monitored Zone	Equipment	Pre / Post Processing requirements	Risk Category	Advantages	Limitations	TRL	Suitable for Subsea CCUS	Exploration & Appraisal	Development	Operations & Maintenance	Decommissioning / Post-decommissioning
Land EM	Electrical resistivity signals used to measure from induction source and receiver array due to CO2 saturation between wells or shallow soil zone	Surface/Near-Surface/Reservoir: Reservoir or soil	At least two wells with string array of electrodes attached to well casing	Baseline, post injection, processing & interpretation of difference	Capacity, containment, contingency	Focused on reservoir zone, more accurate than some other seismic methods, lower processing	Only covers interwell cross section zone, subject to interpretation, requires high CO2 saturation, non-conductive pipe	5	N	N	N	Y	N
Land ERT	Electrical resistivity measurements to determine changes in structure and water saturations due to CO2 injection	Surface/Near-Surface/Reservoir: Ground water and subsurface	Seismic sensors, source arrays, and sources (vibrator trucks/vibrator systems)	Baseline surveys, geocharacteristion, and multiple data processing events	Capacity, containment, contingency	Site characterization prior to injection and time-lapse monitoring to survey potential changes due to CO2 injection. Identification of potential fractures and faults in the subsurface.	small scale faults feature offsets >10 m are not detectable, lacks full surface coverage	5	N	N	N	Y	N
Non dispersive IR gas analysers	Gas meter that measures CO2 concentrations in air based on IR spectroscopy	Atmosphere	Gas meter, data logger system	None	Containment, contingency, public acceptance	Direct measurements, simple technology, high visibility, easy to communicate	Natural CO2 variations, false positives	8	N	N	N	Y	Y
Soil gas concentrations	Monitoring of soil gas composition to detect increases in CO2 levels or other indicators of CO2 leakage	Surface/Near-Surface: Shallow soil zone	Soil gas monitoring points, gas collection equipment, analytical lab services	Baseline, post injection, processing & interpretation of difference	Containment, contingency, mitigation, public acceptance	Direct measurements, simple technology, high visibility, easy to communicate	Natural CO2 variations, false positives	7	N	N	N	Y	Y
Surface gas flux	Monitoring CO2 flux and chemistry as indicator of CO2 leakage from reservoir	Surface/Near-Surface: Shallow soil zone	Gas flux chambers, gas collection equipment, analytical lab services	Baseline, post injection, processing & interpretation of difference	Containment, contingency, mitigation, public acceptance	Direct measurements, simple technology, high visibility, easy to communicate	Natural CO2 variations, false positives	7	N	N	N	Y	Y
Surface Safety/Gas Meters	CO2 gas meters near surface equipment to monitor releases	Atmosphere	CO2 gas meters	None	Containment, contingency, mitigation	Direct measurements, simple technology, high visibility, easy to communicate	Limited to injection site, only provides notice of large equipment failures	8	N	N	N	Y	Y
Tiltmeters	Inclinometer technology which measures deviation from horizontal and vertical plane	Surface/Near-Surface	Tiltmeter and Monitoring Station	Baseline survey, periodic surveys	Containment, contingency, mitigation	Measure surface deformation in proximity to injection sites	Land access, data collection, spurious changes due to temperature and rainfall	7	N	N	N	Y	Y

Appendix 3 Risk Identification and Quantification Output

		Risk Description						Pre-Mitigation Assessment								
ID	Common Element	Risk	Cause	Consequence	Offshore Wind Project Phase	CCUS Project Phase	Notes / Context	Probability	Personnel Impact (P)	Environment Impact (E)	Asset Impact (A)	Reputation Impact (R)	Schedule Impact (H)	Social Impact (S)	Financial Impact (F)	Assessment
001	B	Risk of: Inability to progress site exploration, development and appraisal	Due to: Lack of access to site	Resulting in: Loss of public and investor confidence.	Development Installation & commissioning Operations & maintenance	Exploration & appraisal Development Operations & maintenance	Includes areas such as: - Clashes over who has precedence for access -Delays or inability to progress projects due to access being blocked by co-located activities (some overlap with risk #22) - Potential issues with development timelines for Offshore Wind and CCUS being different (offshore wind being quicker) meaning that co-location not actively considered	4	0	0	0	2	0	0	5	High
002	E	Risk of: Inability to co-locate Offshore Wind with CCUS	Due to: Potential 500 m exclusion zone around CCUS drill centres	Resulting in: "Loss" of seabed area for Offshore Wind developments	Development Installation & commissioning Operations & maintenance Decommissioning	Operations & maintenance	Consideration of exclusion zones is quite a key factor to determine whether it is even possible to co-locate Offshore Wind with CCUS drill centres / infrastructure	3	0	0	0	2	0	0	3	Medium
003	A	Risk of: Loss of fishing grounds	Due to: Unforeseen delays in project implementation due to co-located project issues	Resulting in: Financial impact on project developers plus potential lack of clarity over is responsible for compensation to fishermen	Installation & commissioning	Development	Note that this is a temporary loss of fishing grounds due to the installation period being longer than expected	3	0	0	0	0	0	2	2	Low
004	E	Risk of: Inability to carry out Offshore Wind geophysical surveys during project preparation and / or decommissioning	Due to: Presence of existing CCUS infrastructure	Resulting in: Schedule delays and potential project cancellation	Develop Decommissioning	Operations & maintenance	No further notes	3	0	0	0	2	3	0	2	Medium
005	A	Risk of: Delay to project implementation	Due to: Lack of clarity over who has precedence in co-located sites	Resulting in: Schedule delays and potential project cancellation	Development Installation & commissioning	Exploration & appraisal Development	References back to a clause in Offshore Wind permitting that gives priority to oil and gas developments if there is a discovery; is something similar going to happen with CCUS?; who is given priority?; cross-industry coordination from a regulatory standpoint?	3	0	0	0	2	4	3	2	Medium
006	C	Risk of: Resource constraints for support vessels, personnel, ports, etc.	Due to: Competition for resources between CCUS and Offshore Wind	Resulting in: Schedule delays and increased costs for CCUS and Offshore Wind project developers / operators	Development Installation & commissioning Operations & maintenance Decommissioning	Exploration & appraisal Development Operations & maintenance Decommissioning Post-decom	Includes areas such as: - Potential scarcity of suitable vessels and crew - Ports servicing offshore could become congested due to crew changes for a wide range of vessels	4	0	0	0	0	4	0	2	High
007	C	Risk of: Marine vessel congestion	Due to: Increased traffic at site associated with CCUS, Offshore Wind, fishing and leisure	Resulting in: Potential ship collision with asset infrastructure and other ships	Development Installation & commissioning Operations & maintenance Decommissioning	Exploration & appraisal Development Operations & maintenance Decommissioning Post-decom	Particularly of concern during high activity periods such as offshore construction / decommissioning and major intervention campaigns. Not such a significant concern during "normal" operation, exploration phase or post-decommissioning. Note that construction periods for CCUS and Offshore Wind are likely to be over a number of years, not a single summer campaign. Could also involve considerations for "future" co-located industries such as green hydrogen, aquaculture, etc.	4	3	0	2	0	3	0	2	Medium
008	C	Risk of: Helicopter crash	Due to: Presence of Offshore Wind in CCUS area with poor (foggy) conditions and heliops being required for CCUS.	Resulting in: Major personnel safety risk or delays to CCUS activities	Operations & maintenance	Development Operations & maintenance	Focused around the potential need to access CCUS infrastructure at short notice in foggy conditions (very prevalent in Southern North Sea) when heliops are normally banned for offshore wind due to interaction risk	4	5	2	2	4	0	4	3	High
009	A	Risk of: Reputation competition	Due to: Public perception that Offshore Wind is more green than CCUS	Resulting in: Precedence given to Offshore Wind over CCUS	Development Installation & commissioning	Exploration & appraisal Development	No further notes	4	0	0	0	3	0	3	3	Medium
010	A	Risk of: Cross asset reputation impact	Due to: Incident at co-located site	Resulting in: Loss of investor confidence in site that isn't source of incident, unwanted public attention	Development Installation & commissioning Operations & maintenance Decommissioning	Exploration & appraisal Development Operations & maintenance Decommissioning Post-decom	No further notes	3	0	0	0	3	3	3	3	Medium
011	E	Risk of: Damage to other marine users from infrastructure left on seabed following decommissioning	Due to: Lack of clarity over regulatory regime for CCUS and Offshore Wind	Resulting in: Risk to personnel	Operations & maintenance Decommissioning	Operations & maintenance Decommissioning Post-decom	Focused around the potential for cable/pipeline infrastructure to be left in-situ following decommissioning in areas where it crosses co-located infrastructure that is still live	4	3	2	0	3	0	3	3	Medium
012	C	Risk of: Overall area environmental impacts being increased	Due to: Environmental impacts of developments / operations being combined at co-located sites and worse than separate sites	Resulting in: Increased risk to environment	Development Installation & commissioning Operations & maintenance Decommissioning	Exploration & appraisal Development Operations & maintenance Decommissioning Post-decom	No further notes	4	0	3	0	3	0	3	3	Medium
013	D	Risk of: Leak from CCUS infrastructure	Due to: Offshore Wind activities	Resulting in: Liability/financial impact on CCUS operator.	Development Installation & commissioning Operations & maintenance Decommissioning	Operations & maintenance Decommissioning	Focused on infrastructure leaks from CCUS rather than a gross reservoir release. Interaction with offshore wind activities such as major maintenance regimes (dropped objects), snagging of infrastructure from anchoring, vessel collision, etc. Particular potential well issue if full piles need to be removed for wind turbines via vibration pull.	4	3	4	3	4	0	4	3	High
014	D	Risk of: Leak from CCUS infrastructure	Due to: Failure of CCUS subsea infrastructure / wells / store	Resulting in: Personnel risk to in-field operations, unplanned cessation of in-field operations for Offshore Wind.	Installation & commissioning Operations & maintenance Decommissioning	Operations & maintenance Decommissioning	No further notes	3	5	5	5	4	0	4	3	High

		Risk Description						Pre-Mitigation Assessment								
ID	Common Element	Risk	Cause	Consequence	Offshore Wind Project Phase	CCUS Project Phase	Notes / Context	Probability	Personnel Impact (P)	Environment Impact (E)	Asset Impact (A)	Reputation Impact (R)	Schedule Impact (H)	Social Impact (S)	Financial Impact (F)	Assessment
015	D	Risk of: Seabed geophysical changes	Due to: Issues with CCUS storage site	Resulting in: Damage to Offshore Wind Infrastructure and/or change to decommissioning, survey requirements	Development Installation & commissioning Operations & maintenance	Operations & maintenance Decommissioning Post-decom	Potential for seabed "heave" due to CCUS storage. Reverse (i.e. seabed sink) previously seen in some shallow hydrocarbon reservoirs	3	0	0	4	4	4	3	4	Medium
016	D	Risk of: Corrosion of Offshore Wind infrastructure	Due to: Saline aquifer brine release from CCUS operations	Resulting in: Damage to Offshore Wind Infrastructure	Operations & maintenance	Operations & maintenance	Note that, while reservoir brine is likely significantly more saline than seawater, any corrosive effect will quickly disperse and would be highly unlikely to extend to sea surface (where water is oxygenated and corrosion more likely to occur)	2	0	0	3	3	0	3	4	Medium
017	E	Risk of: Restricted access to drill relief well in the event of CCUS leak	Due to: Access being blocked by Offshore Wind infrastructure	Resulting in: Extended CO2 release from CCUS store	Operations & maintenance	Operations & maintenance Decommissioning Post-decom	Note that "relief well" tophole location will need to be separate from injector wells and drilling rig will need anchorage if semi-sub or seabed location for jack-up rig.	3	3	5	5	5	0	4	5	High
018	E	Risk of: Restricted access to CCUS infrastructure	Due to: Access being blocked by Offshore Wind infrastructure	Resulting in: Inability to carry out CCUS operational activities (e.g. well workover, inspection, maintenance, etc.)	Operations & maintenance	Operations & maintenance	No further notes	4	0	0	3	2	0	1	3	Medium
019	D	Risk of: Damage to Offshore Wind infrastructure	Due to: CCUS activities including drilling of wells, seismic operations, etc.	Resulting in: Liability/financial impact on Offshore Wind operator	Operations & maintenance	Exploration & appraisal Development Operations & maintenance Decommissioning Post-decom	No further notes	3	0	0	4	3	0	2	4	Medium
020	-	Risk of: Difficulty in gaining insurance cover	Due to: Inability to properly categorise and quantify risks for co-developed areas	Resulting in: Increased insurance premiums	Development Installation & commissioning Operations & maintenance	Exploration & appraisal Development Operations & maintenance	No further notes	3	0	0	0	2	2	0	3	Medium
021	A	Risk of: Lack of clarity over-fishing interaction issues	Due to: Seabed infrastructure during operation or post-decommissioning	Resulting in: Unforeseen costs to CCUS or Offshore Wind operators	Operations & maintenance Decommissioning	Operations & maintenance Decommissioning Post-decom	Particularly of concern in post-decommissioning phase if a co-located asset continues to operate in the area. Potential confusion over what caused incident and who should pay compensation. May be of particular concern for floating offshore wind due to larger seabed area.	3	0	0	0	2	0	2	2	Low
022	A	Risk of: Extended project implementation schedule	Due to: Co-location of Offshore Wind and CCUS projects	Resulting in: Financial/regulatory impact on developing operator	Development Installation & commissioning	Exploration & appraisal Development	No further notes	4	0	0	0	2	4	3	3	High
023	A	Risk of: Poor project execution	Due to: Unclear or conflicting permitting / consent regime for co-located projects	Resulting in: Financial and schedule impact on developing operator	Development Installation & commissioning	Exploration & appraisal Development	Potential for different stakeholders for Offshore Wind and CCUS but also potential for confusion of messages to common stakeholders	4	0	0	0	2	4	3	3	High
024	C	Risk of: Poor management of shared resources	Due to: Unclear "ownership" and prioritisation of shared resources such as emergency response, logistics and infrastructure (such as power)	Resulting in: Increased operational costs to operators	Development Installation & commissioning Operations & maintenance Decommissioning	Exploration & appraisal Development Operations & maintenance Decommissioning Post-decom	No further notes	3	0	0	0	2	0	0	2	Low
025	C	Risk of: Overall area noise limits being exceeded	Due to: Cumulative impact of multiple operations	Resulting in: Potential fines to operators and impacts on local environment	Development Installation & commissioning Operations & maintenance Decommissioning	Exploration & appraisal Development Operations & maintenance Decommissioning Post-decom	No further notes	3	0	3	0	4	0	0	2	Medium
026	E	Risk of: Requirement to modify existing infrastructure	Due to: Access / infrastructure requirements of new CCUS or Offshore Wind development	Resulting in: Financial impact on existing infrastructure operator	Development Installation & commissioning Operations & maintenance	Exploration & appraisal Development Operations & maintenance	Focused around the need to change what has already been installed to accommodate new infrastructure or access requirements for a co-located project	3	0	0	0	2	3	0	3	Medium
027	E	Risk of: Need to install or remove more infrastructure than "ideal", including future CCUS expansion	Due to: Presence of existing or planned CCUS or Offshore Wind development	Resulting in: Financial impact on developing operator	Development Installation & commissioning Operations & maintenance	Exploration & appraisal Development Operations & maintenance	Includes consideration of issues such as: - Will "existing" infrastructure change over the long development period of either of these types of project resulting in the "new" project needing to be amended to suit? - Any anchor CCUS project is likely going to want to expand to a new store in future while utilising the same pipeline connection to shore - Potential for offshore wind ambition to re-use infrastructure to support future industries such as aquaculture leading to seabed area being excluded for CCUS for a longer period - Equally, CCUS could potentially leave major infrastructure, such as large bore pipelines, on the seabed blocking future Offshore Wind	3	0	0	0	2	3	0	3	Medium
028	C	Risk of: Poor coordination of activities between developers	Due to: Complex schedules required for CCUS and Offshore Wind developments and operations being difficult to align	Resulting in: Financial and safety impacts on both CCUS and Offshore Wind operators	Development Installation & commissioning Operations & maintenance	Exploration & appraisal Development Operations & maintenance	No further notes	4	3	0	1	2	3	0	3	Medium

		Risk Description						Pre-Mitigation Assessment								
ID	**Common Element**	**Risk**	**Cause**	**Consequence**	**Offshore Wind Project Phase**	**CCUS Project Phase**	**Notes / Context**	**Probability**	**Personnel Impact (P)**	**Environment Impact (E)**	**Asset Impact (A)**	**Reputation Impact (R)**	**Schedule Impact (H)**	**Social Impact (S)**	**Financial Impact (F)**	**Assessment**
029	B	Risk of: Restricted access to CCUS storage site for towed streamer seismic surveys	Due to: Current, planned or future potential Offshore Wind infrastructure (note that this could be worse for floating offshore wind)	Resulting in: Most likely to inability to carry out planned towed streamer survey. At best, increased costs for towed streamer survey & difficulty in getting suitably "repeatable" seismic survey results	Operations & maintenance	Exploration & appraisal Development Operations & maintenance Decommissioning Post-decom	Note that "general" towed streamer seismic surveys would have an array of receivers stretching back circa 5 kilometres behind vessel with a width in the order of 1 kilometre and can drift by 500 metres due to local conditions. Also need a large turning circle for this type of survey. Windfarm spacing in the region of 500 metres to 1 kilometre over large seabed area (up to 100 turbines) Also note seismic surveys usually extend 5 kilometres beyond the immediate limits of a CCUS store.	5	0	0	0	2	3	3	3	High
030	B	Risk of: Poor quality CCUS seismic monitoring	Due to: Noise interaction from Offshore Wind infrastructure / operations and structural movement of turbines	Resulting in: Inability to properly monitor CCUS storage, potential financial penalties on CCUS operator.	Installation & commissioning Operations & maintenance	Exploration & appraisal Development Operations & maintenance Decommissioning Post-decom	Seismic quality can be potentially affected by: - Ambient noise from wind turbines - Noise from piling operations (can be in a nearby area, not necessarily at the same site) - Physical reflections from wind turbine sub-structure piles - Diving precludes and fishing limits seismic acquisition	4	0	0	2	4	0	3	5	High
031	B	Risk of: Inability to co-locate Offshore Wind with existing CCUS	Due to: Seismic survey operations prohibiting access to CCUS area for Offshore Wind developments	Resulting in: "Loss" of seabed area for Offshore Wind developments	Development Installation & commissioning	Operations & maintenance Decommissioning Post-decom	Loss of seabed for Offshore Wind results in increased Levelised Cost of Electricity to produce electricity when sterilised seabed is part of an existing Offshore Wind lease area; this impacts how competitive the Offshore Wind project is in subsidy auction rounds	4	0	0	0	4	0	3	4	High
032	B	Risk of: Damage to Offshore Wind infrastructure	Due to: seismic monitoring operations	Resulting in: Financial impact on Offshore Wind and CCUS operator	Operations & maintenance	Exploration & appraisal Development Operations & maintenance Decommissioning Post-decom	For example, on bottom seismic node placed close to Offshore Wind infrastructure on "rope" or by remote operated vehicle. Possible collision or snagging on other seabed equipment. Source feathers collide with wind substructure or dragged across other infrastructure Damage caused by airgun pulses Note that sound sources for both towed streamer and on bottom node seismic are currently towed 100 metres behind a vessel at a water depth of 3-4 metres. Current technology does not involve seabed sound sources.	2	0	0	2	2	0	2	3	Low
033	B	Risk of: Restricted access to CCUS storage site for "other" storage site surveys	Due to: Current or planned Offshore Wind operations	Resulting in: Inability to carry out planned seismic survey, increased costs for seismic survey, difficulty in getting suitably "repeatable" seismic survey results	Development Installation & commissioning Operations & maintenance	Exploration & appraisal Development Operations & maintenance Decommissioning Post-decom	No further notes	3	0	0	0	2	3	2	3	Medium
034	-	Risk of: Lack of knowledge retention / lessons learned for SIMOPS	Due to: Long periods between installation and decommissioning activities for CCUS and Offshore Wind	Resulting in: Poor project execution	Installation & commissioning Operations & maintenance Decommissioning	Development Operations & maintenance Decommissioning Post-decom	No further notes	4	0	0	3	3	3	2	3	Medium
035	C	Risk of: Poor response to 3rd party emergency in area	Due to: Lack of emergency response coordination between CCUS and Offshore Wind developers	Resulting in: Potential personnel risk for 3rd parties plus financial/liability issues for CCUS and Offshore Wind operators	Installation & commissioning Operations & maintenance Decommissioning	Development Operations & maintenance Decommissioning Post-decom	No further notes	3	4	0	0	4	0	4	3	Medium
036	C	Risk of: Safety impact on divers during operations	Due to: Uncoordinated operations between CCUS and Offshore Wind developers	Resulting in: Potential major injury or loss of life for divers, schedule delays	Installation & commissioning Operations & maintenance Decommissioning	Development Operations & maintenance Decommissioning	Particularly of concern during decommissioning of a co-located asset during operation of other assets	4	4	0	0	4	2	4	3	High
037	D	Risk of: Damage to CCUS infrastructure	Due to: Offshore Wind activities	Resulting in: Financial impact on CCUS operator, potential leak from infrastructure (reference risk 013)	Installation & commissioning Operations & maintenance Decommissioning	Operations & maintenance	Potential sources of damage include: - Jack-up rig legs during offshore wind installation - Dropped objects during offshore wind maintenance - Interaction with piling operations (vibration) for new offshore wind infrastructure - Potential vibration impact from normal turbine operations Includes potential damage to seabed monitoring infrastructure for CCUS as this could be particularly vulnerable	4	3	3	4	4	0	4	2	High
038	A	Risk of: Decommissioning programme "incomplete"	Due to: Co-location of Offshore Wind and CCUS infrastructure	Resulting in: Lack of clarity over who "owns" decommissioned infrastructure left in-situ	Operations & maintenance Decommissioning	Operations & maintenance Decommissioning Post-decom	Focused around the potential for cable/pipeline infrastructure to be left in-situ following decommissioning in areas where it crosses co-located infrastructure that is still live	3	0	2	0	3	3	2	3	Medium
039	A	Risk of: Unforeseen project installation delays	Due to: Vendor delivery periods changing in co-located project	Resulting in: Financial / liability impact across projects (who pays for delays?)	Installation & commissioning	Development	No further notes	4	0	0	0	4	4	3	3	High

		Risk Description						Pre-Mitigation Assessment								
ID	Common Element	Risk	Cause	Consequence	Offshore Wind Project Phase	CCUS Project Phase	Notes / Context	Probability	Personnel Impact (P)	Environment Impact (E)	Asset Impact (A)	Reputation Impact (R)	Schedule Impact (H)	Social Impact (S)	Financial Impact (F)	Assessment
040	A	Risk of: Cross asset schedule delays	Due to: Less certainty over life expectancy of CCUS	Resulting in: Financial / liability impact across projects (who pays for delays?)	Installation & commissioning Operations & maintenance	Operations & maintenance Decommissioning	No further notes	4	0	0	0	4	4	3	3	High
041	E	Risk of: Inability to co-locate CCUS with Offshore Wind	Due to: Offshore Wind significantly extending operational lease	Resulting in: "Loss" of potential CCUS storage volumes	Operations & maintenance	Exploration & appraisal Development	Potential to re-use substructure and cable infrastructure to house new turbines at end of lease period preventing CCUS from "taking over" seabed.	3	0	0	0	4	0	3	5	High
042	C	Risk of: Temporary interruption to CCUS activities	Due to: Asset / safety risk associated with Offshore Wind construction or decommissioning activities	Resulting in: Financial impact on CCUS operator, potential venting of CO2 to atmosphere, etc.	Installation & commissioning Operations & maintenance Decommissioning	Operations & maintenance	No further notes	4	0	0	3	3	0	2	3	Medium
043	A	Risk of: Future legislation impacts on co-located projects	Due to: Changes in regulator decommissioning requirements for CCUS and Offshore Wind	Resulting in: Inability to proceed with new CCUS / Offshore Wind projects	Operations & maintenance Decommissioning	Operations & maintenance Decommissioning Post-decom	No further notes	4	0	0	0	3	3	2	3	Medium
044	A	Risk of: Competition for subsidies	Due to: Funding requirements from CCUS and Offshore Wind potentially coming from same "pot"	Resulting in: Inability to proceed with new CCUS / Offshore Wind projects	Development Installation & commissioning Operations & maintenance	Exploration & appraisal Development Operations & maintenance	No further notes	3	0	0	0	3	0	3	4	Medium
045	A	Risk of: Damage to environment from infrastructure left on seabed following decommissioning	Due to: Lack of clarity over regulatory regime for CCUS and Offshore Wind	Resulting in: Sustained environmental impact	Operations & maintenance Decommissioning	Operations & maintenance Decommissioning Post-decom	Focused around the potential for cable/pipeline infrastructure to be left in-situ following decommissioning in areas where it crosses co-located infrastructure that is still live	3	0	3	0	3	0	3	3	Medium
046	D	Risk of: Hydrocarbons breach aquifer/ surface	Due to: Reservoir methane propelled by over-pressurised CO2	Resulting in: Cratering, gas escape. Undermines windfarm integrity/ risk of explosion	Development Installation & commissioning Operations & maintenance Decommissioning	Operations & maintenance Decommissioning Post-decom	No further notes	2	1	5	1	5	0	3	4	Medium

Appendix 4 Risk Mitigation Output – Good Practice Mitigation Measures

		Risk Description				Post-Mitigation Assessment								
ID	Common Element	Risk	Cause	Consequence	Good Practice Mitigation	Good Practice Probability	Personnel Impact (P)	Environment Impact (E)	Asset Impact (A)	Reputation Impact (R)	Schedule Impact (H)	Social Impact (S)	Financial Impact (F)	Good Practice Assessment
001	B	Risk of: Inability to progress site exploration, development and appraisal	Due to: Lack of access to site	Resulting in: Loss of public and investor confidence.		4	0	0	0	2	0	0	5	High
002	E	Risk of: Inability to co-locate Offshore Wind with CCUS	Due to: Potential 500 m exclusion zone around CCUS drill centres	Resulting in: "Loss" of seabed area for Offshore Wind developments	- Adjust / arrange offshore wind infrastructure to accommodate CCUS exclusion zones and minimise exclusion zone requirements	2	0	0	0	2	0	0	3	Low
003	A	Risk of: Loss of fishing grounds	Due to: Unforeseen delays in project implementation due to co-located project issues	Resulting in: Financial impact on project developers plus potential lack of clarity over is responsible for compensation to fishermen	- Effective planning of projects but this doesn't really reduce the potential likelihood due to the "unforeseen delays" part	3	0	0	0	0	0	2	2	Low
004	E	Risk of: Inability to carry out Offshore Wind geophysical surveys during project preparation and / or decommissioning	Due to: Presence of existing CCUS infrastructure	Resulting in: Schedule delays and potential project cancellation	- Unlikely that CCUS infrastructure will block significant areas of seabed, so good co-ordination across Offshore Wind and CCUS operators should enable surveys to go ahead	1	0	0	0	2	3	0	2	Low
005	A	Risk of: Delay to project implementation	Due to: Lack of clarity over who has precedence in co-located sites	Resulting in: Schedule delays and potential project cancellation	- Cross-industry co-ordination	2	0	0	0	2	4	3	2	Medium
006	C	Risk of: Resource constraints for support vessels, personnel, ports, etc.	Due to: Competition for resources between CCUS and Offshore Wind	Resulting in: Schedule delays and increased costs for CCUS and Offshore Wind project developers / operators	- Engage with supply chain to minimise resource issues across industries (e.g. dive support vessel action groups being set up for oil and gas industry). - Investment in local area with apprentice and retraining programs.	3	0	0	0	0	4	0	2	Medium
007	C	Risk of: Marine vessel congestion	Due to: Increased traffic at site associated with CCUS, Offshore Wind, fishing and leisure	Resulting in: Potential ship collision with asset infrastructure and other ships	- Cross-industry co-ordination	2	3	0	2	0	3	0	2	Low
008	C	Risk of: Helicopter crash	Due to: Presence of Offshore Wind in CCUS area with poor (foggy) conditions and heliops being required for CCUS.	Resulting in: Major personnel safety risk or delays to CCUS activities	- Assess whether there is an overarching operational requirement for heliops access to CCUS platforms during foggy conditions (note that oil and gas platforms don't currently allow heliops access in heavy fog). - Enforce minimum height fly zone for heliops over Offshore Wind infrastructure	2	5	2	2	4	0	4	3	Medium
009	A	Risk of: Reputation competition	Due to: Public perception that Offshore Wind is more green than CCUS	Resulting in: Precedence given to Offshore Wind over CCUS	- Difficult to mitigate against other than public education	4	0	0	0	3	0	3	3	Medium
010	A	Risk of: Cross asset reputation impact	Due to: Incident at co-located site	Resulting in: Loss of investor confidence in site that isn't source of incident, unwanted public attention	- Good co-ordination between projects	2	0	0	0	3	3	3	3	Low
011	E	Risk of: Damage to other marine users from infrastructure left on seabed following decommissioning	Due to: Lack of clarity over regulatory regime for CCUS and Offshore Wind	Resulting in: Risk to personnel		4	3	2	0	3	0	3	3	Medium
012	C	Risk of: Overall area environmental impacts being increased	Due to: Environmental impacts of developments / operations being combined at co-located sites and worse than separate sites	Resulting in: Increased risk to environment	- Ensure that cumulative environmental impacts are assessed as part of Environmental approvals process for project; if this is the case, unlikely that this could occur without it being known beforehand - Continuous monitoring - Detailed recording of any and all environmental impact (recordable)	2	0	3	0	3	0	3	3	Low
013	D	Risk of: Leak from CCUS infrastructure	Due to: Offshore Wind activities	Resulting in: Liability/financial impact on CCUS operator.	- Use lessons learned from oil and gas industry regarding dropped objects interaction and interaction with marine traffic - Provide dropped object protection and "fishsafe" designs for CCUS infrastructure that would be particularly vulnerable (e.g. subsea manifolds and wellheads) - Provide exclusion zones around vulnerable CCUS infrastructure that limits the size / weight of dropped object that could interact with CCUS infrastructure - Ensure proper lifting plans, risk assessments, competent people, competent contractors and controls are in place for all relevant offshore wind construction and maintenance activities	2	3	4	3	4	0	4	3	Medium
014	D	Risk of: Leak from CCUS infrastructure	Due to: Failure of CCUS subsea infrastructure / wells / store	Resulting in: Personnel risk to in-field operations, unplanned cessation of in-field operations for Offshore Wind.	- Difficult to mitigate against any co-location issues. All CCUS projects will have to adopt a fairly intensive monitoring regime and have intervention plans in place. The risk to personnel could potentially be mitigated against by enforcing exclusion zones around CCUS drill centres.	3	5	5	5	4	0	4	3	High
015	D	Risk of: Seabed geophysical changes	Due to: Issues with CCUS storage site	Resulting in: Damage to Offshore Wind Infrastructure and/or change to decommissioning, survey requirements	- Difficult to mitigate against this other than to have a detailed monitoring programme in place; may drive requirement for floating wind instead of fixed wind in co-located areas	3	0	0	4	4	4	3	4	Medium
016	D	Risk of: Corrosion of Offshore Wind infrastructure	Due to: Saline aquifer brine release from CCUS operations	Resulting in: Damage to Offshore Wind Infrastructure	- Ensure water relief wells are drilled away from offshore wind infrastructure where possible	2	0	0	3	3	0	3	4	Medium
017	E	Risk of: Restricted access to drill relief well in the event of CCUS leak	Due to: Access being blocked by Offshore Wind infrastructure	Resulting in: Extended CO2 release from CCUS store	- Ensure that any Offshore Wind turbine and seabed infrastructure is arranged to allow sufficient room for rig intervention access - Ensure that CCUS project developments nominate rig intervention location requirements during project planning and ensure that these areas are kept clear of Offshore Wind infrastructure	1	3	5	5	5	0	4	5	Medium

		Risk Description				Post-Mitigation Assessment								
ID	Common Element	Risk	Cause	Consequence	Good Practice Mitigation	Good Practice Probability	Personnel Impact (P)	Environment Impact (E)	Asset Impact (A)	Reputation Impact (R)	Schedule Impact (H)	Social Impact (S)	Financial Impact (F)	Good Practice Assessment
018	E	Risk of: Restricted access to CCUS infrastructure	Due to: Access being blocked by Offshore Wind infrastructure	Resulting in: Inability to carry out CCUS operational activities (e.g. well workover, inspection, maintenance, etc.)	- Ensure co-location access is considered during project development	2	0	0	3	2	0	1	3	Low
019	D	Risk of: Damage to Offshore Wind infrastructure	Due to: CCUS activities including drilling of wells, seismic operations, etc.	Resulting in: Liability/financial impact on Offshore Wind operator		3	0	0	4	3	0	2	4	Medium
020	-	Risk of: Difficulty in gaining insurance cover	Due to: Inability to properly categorise and quantify risks for co-developed areas	Resulting in: Increased insurance premiums		3	0	0	0	2	2	0	3	Medium
021	A	Risk of: Lack of clarity over-fishing interaction issues	Due to: Seabed infrastructure during operation or post-decommissioning	Resulting in: Unforeseen costs to CCUS or Offshore Wind operators		3	0	0	0	2	0	2	2	Low
022	A	Risk of: Extended project implementation schedule	Due to: Co-location of Offshore Wind and CCUS projects	Resulting in: Financial/regulatory impact on developing operator		4	0	0	0	2	4	3	3	High
023	A	Risk of: Poor project execution	Due to: Unclear or conflicting permitting / consent regime for co-located projects	Resulting in: Financial and schedule impact on developing operator		4	0	0	0	2	4	3	3	High
024	C	Risk of: Poor management of shared resources	Due to: Unclear "ownership" and prioritisation of shared resources such as emergency response, logistics and infrastructure (such as power)	Resulting in: Increased operational costs to operators	- Mitigation would be good co-ordination across industries - more of an opportunity but the risk here is that the savings of co-ordination aren't as large as expected	2	0	0	0	2	0	0	2	Low
025	C	Risk of: Overall area noise limits being exceeded	Due to: Cumulative impact of multiple operations	Resulting in: Potential fines to operators and impacts on local environment	- Ensure that cumulative noise impacts are assessed as part of Environmental approvals process for project; if this is the case, unlikely that this could occur without it being known beforehand	1	0	3	0	4	0	0	2	Low
026	E	Risk of: Requirement to modify existing infrastructure	Due to: Access / infrastructure requirements of new CCUS or Offshore Wind development	Resulting in: Financial impact on existing infrastructure operator		3	0	0	0	2	3	0	3	Medium
027	E	Risk of: Need to install or remove more infrastructure than "ideal", including future CCUS expansion	Due to: Presence of existing or planned CCUS or Offshore Wind development	Resulting in: Financial impact on developing operator		3	0	0	0	2	3	0	3	Medium
028	C	Risk of: Poor coordination of activities between developers	Due to: Complex schedules required for CCUS and Offshore Wind developments and operations being difficult to align	Resulting in: Financial and safety impacts on both CCUS and Offshore Wind operators		4	3	0	1	2	3	0	3	Medium
029	B	Risk of: Restricted access to CCUS storage site for towed streamer seismic surveys	Due to: Current, planned or future potential Offshore Wind infrastructure (note that this could be worse for floating offshore wind)	Resulting in: Most likely to inability to carry out planned towed streamer survey. At best, increased costs for towed streamer survey & difficulty in getting suitably "repeatable" seismic survey results		5	0	0	0	2	3	3	3	High
030	B	Risk of: Poor quality CCUS seismic monitoring	Due to: Noise interaction from Offshore Wind infrastructure / operations and structural movement of turbines	Resulting in: Inability to properly monitor CCUS storage, potential financial penalties on CCUS operator.	- Ensure that seismic data acquisition is scheduled so that it does not coincide with offshore wind construction activities. - Plan seismic monitoring with planned Offshore Wind major maintenance campaigns so that turbines are down and limit losses if other turbines are switched off. - Power down wind turbines.	4	0	0	2	4	0	3	5	High
031	B	Risk of: Inability to co-locate Offshore Wind with existing CCUS	Due to: Seismic survey operations prohibiting access to CCUS area for Offshore Wind developments	Resulting in: "Loss" of seabed area for Offshore Wind developments		4	0	0	0	4	0	3	4	High
032	B	Risk of: Damage to Offshore Wind infrastructure	Due to: seismic monitoring operations	Resulting in: Financial impact on Offshore Wind and CCUS operator		2	0	0	2	2	0	2	3	Low
033	B	Risk of: Restricted access to CCUS storage site for "other" storage site surveys	Due to: Current or planned Offshore Wind operations	Resulting in: Inability to carry out planned seismic survey, increased costs for seismic survey, difficulty in getting suitably "repeatable" seismic survey results		3	0	0	0	2	3	2	3	Medium
034	-	Risk of: Lack of knowledge retention / lessons learned for SIMOPS	Due to: Long periods between installation and decommissioning activities for CCUS and Offshore Wind	Resulting in: Poor project execution	- Implement effective succession planning and knowledge retention within CCUS and Offshore Wind projects to avoid this - good corporate practice in any case - Implement lessons learned from oil and gas industry when assets have changed hands - Keep up to date records of drawings etc.	2	0	0	3	3	3	2	3	Medium
035	C	Risk of: Poor response to 3rd party emergency in area	Due to: Lack of emergency response coordination between CCUS and Offshore Wind developers	Resulting in: Potential personnel risk for 3rd parties plus financial/liability issues for CCUS and Offshore Wind operators	- Good co-ordination between CCUS and Offshore Wind operators on the same location - More of an opportunity than a risk as each developer would have to have in place their own specific emergency response measures as a minimum that take account of local area; co-ordination of response across industries can only be an improvement on that - Training to cover joint emergency response - Training exercises between both parties	2	4	0	0	4	0	4	3	Medium
036	C	Risk of: Safety impact on divers during operations	Due to: Uncoordinated operations between CCUS and Offshore Wind developers	Resulting in: Potential major injury or loss of life for divers, schedule delays	- Standard diver access control measures but need co-ordination across different projects - Both parties included within planning and risk assessment stages to share knowledge.	2	4	0	0	4	2	4	4	Medium

ID	Common Element	Risk Description: Risk	Risk Description: Cause	Risk Description: Consequence	Good Practice Mitigation	Post-Mitigation Assessment: Good Practice Probability	Personnel Impact (P)	Environment Impact (E)	Asset Impact (A)	Reputation Impact (R)	Schedule Impact (H)	Social Impact (S)	Financial Impact (F)	Good Practice Assessment
037	D	Risk of: Damage to CCUS infrastructure	Due to: Offshore Wind activities	Resulting in: Financial impact on CCUS operator, potential leak from infrastructure (reference risk 013)	- Use lessons learned from oil and gas industry regarding dropped objects interaction and interaction with marine traffic - Provide dropped object protection and "fish safe" designs for CCUS infrastructure that would be particularly vulnerable (e.g. subsea manifolds and wellheads) - Provide exclusion zones around vulnerable CCUS infrastructure that limit the size / weight of dropped object that could interact with CCUS infrastructure - Ensure proper lifting plans and controls are in place for all relevant offshore wind construction and maintenance activities	2	3	3	4	4	0	4	2	Medium
038	A	Risk of: Decommissioning programme "incomplete"	Due to: Co-location of Offshore Wind and CCUS infrastructure	Resulting in: Lack of clarity over who "owns" decommissioned infrastructure left in-situ		3	0	2	0	3	3	2	3	Medium
039	A	Risk of: Unforeseen project installation delays	Due to: Vendor delivery periods changing in co-located project	Resulting in: Financial / liability impact across projects (who pays for delays?)	- Good co-ordination between projects	4	0	0	0	4	4	3	3	High
040	A	Risk of: Cross asset schedule delays	Due to: Less certainty over life expectancy of CCUS	Resulting in: Financial / liability impact across projects (who pays for delays?)	- Good co-ordination between projects	4	0	0	0	4	4	3	3	High
041	E	Risk of: Inability to co-locate CCUS with Offshore Wind	Due to: Offshore Wind significantly extending operational lease	Resulting in: "Loss" of potential CCUS storage volumes		3	0	0	0	4	0	3	5	High
042	C	Risk of: Temporary interruption to CCUS activities	Due to: Asset / safety risk associated with Offshore Wind construction or decommissioning activities	Resulting in: Financial impact on CCUS operator, potential venting of CO2 to atmosphere, etc.	- Similar mitigations to the issue with potential damage to CCUS subsea infrastructure by offshore wind construction/maintenance/decom activities - Lifting plans - Dropped object protection structures - etc.	3	0	0	3	3	0	2	3	Medium
043	A	Risk of: Future legislation impacts on co-located projects	Due to: Changes in regulator decommissioning requirements for CCUS and Offshore Wind	Resulting in: Inability to proceed with new CCUS / Offshore Wind projects		4	0	0	0	3	3	2	3	Medium
044	A	Risk of: Competition for subsidies	Due to: Funding requirements from CCUS and Offshore Wind potentially coming from same "pot"	Resulting in: Inability to proceed with new CCUS / Offshore Wind projects	No significant mitigations identified	3	0	0	0	3	0	3	4	Medium
045	A	Risk of: Damage to environment from infrastructure left on seabed following decommissioning	Due to: Lack of clarity over regulatory regime for CCUS and Offshore Wind	Resulting in: Sustained environmental impact		3	0	3	0	3	0	3	3	Medium
046	D	Risk of: Hydrocarbons breach aquifer/ surface	Due to: Reservoir methane propelled by over-pressurised CO2	Resulting in: Cratering, gas escape. Undermines windfarm integrity/ risk of explosion	- Mitigation would be effective monitoring and verification scheme plus thorough characterisation of store - don't think that changes the potential severity or likelihood though	2	1	5	1	5	0	3	4	Medium

Appendix 5 Risk Mitigation Output – Future Mitigation Measures

		Risk Description				Post-Mitigation Assessment								
ID	Common Element	Risk	Cause	Consequence	Future Practice Mitigation	Future Practice Probability	Personnel Impact (P)	Environment Impact (E)	Asset Impact (A)	Reputation Impact (R)	Schedule Impact (H)	Social Impact (S)	Financial Impact (F)	Future Practice Assessment
001	B	Risk of: Inability to progress site exploration, development and appraisal	Due to: Lack of access to site	Resulting in: Loss of public and investor confidence.	- Pro-actively review potential CCUS and Offshore Wind overlap sites (i.e. where are the good CCUS stores vs the good Offshore Wind sites) and ensure that a combined approach is given to planning and approval of new developments in these area - Appointment of a common body to oversee planning of co-located CCUS and Offshore Wind would greatly enable this - Potential requirement for any new CCUS or Offshore Wind development to assess whether it is likely there could be co-development in the area and plan accordingly - Issue period of notice for co-locating opportunities within development stages for both parties	3	0	0	0	2	0	0	5	High
002	E	Risk of: Inability to co-locate Offshore Wind with CCUS	Due to: Potential 500 m exclusion zone around CCUS drill centres	Resulting in: "Loss" of seabed area for Offshore Wind developments		2	0	0	0	2	0	0	3	Low
003	A	Risk of: Loss of fishing grounds	Due to: Unforeseen delays in project implementation due to co-located project issues	Resulting in: Financial impact on project developers plus potential lack of clarity over is responsible for compensation to fishermen		3	0	0	0	0	0	2	2	Low
004	E	Risk of: Inability to carry out Offshore Wind geophysical surveys during project preparation and / or decommissioning	Due to: Presence of existing CCUS infrastructure	Resulting in: Schedule delays and potential project cancellation	- Common oversight body across industries to help mediate any disputes and be understanding if there are physical limitations - Potential to share survey data	1	0	0	0	2	3	0	2	Low
005	A	Risk of: Delay to project implementation	Due to: Lack of clarity over who has precedence in co-located sites	Resulting in: Schedule delays and potential project cancellation	- Potential for a common oversight body to mediate between co-located projects	2	0	0	0	2	4	3	2	Medium
006	C	Risk of: Resource constraints for support vessels, personnel, ports, etc.	Due to: Competition for resources between CCUS and Offshore Wind	Resulting in: Schedule delays and increased costs for CCUS and Offshore Wind project developers / operators	- Set up independent group to review planning opportunities between both parties.	3	0	0	0	0	4	0	2	Medium
007	C	Risk of: Marine vessel congestion	Due to: Increased traffic at site associated with CCUS, Offshore Wind, fishing and leisure	Resulting in: Potential ship collision with asset infrastructure and other ships	- Potential for a common oversight body to mediate between co-located projects	2	3	0	2	0	3	0	2	Low
008	C	Risk of: Helicopter crash	Due to: Presence of Offshore Wind in CCUS area with poor (foggy) conditions and heliops being required for CCUS.	Resulting in: Major personnel safety risk or delays to CCUS activities	- Ensure any CCUS "platforms" incorporate secondary access (e.g. ship access) within operations plan - Potentially ensure approach corridors are designed into wind farm layouts around CCUS platforms	2	5	2	2	4	0	4	3	Medium
009	A	Risk of: Reputation competition	Due to: Public perception that Offshore Wind is more green than CCUS	Resulting in: Precedence given to Offshore Wind over CCUS		4	0	0	0	3	0	3	3	Medium
010	A	Risk of: Cross asset reputation impact	Due to: Incident at co-located site	Resulting in: Loss of investor confidence in site that isn't source of incident, unwanted public attention	- Potential for a common oversight body to mitigate against this for co-located projects. - Potential for single stakeholder management process for co-located projects - Potential for co-ordinated press release and stakeholder management training	2	0	0	0	3	3	3	3	Low
011	E	Risk of: Damage to other marine users from infrastructure left on seabed following decommissioning	Due to: Lack of clarity over regulatory regime for CCUS and Offshore Wind	Resulting in: Risk to personnel	- Clarify regulatory regime for both industries and harmonise in common areas and agree decommissioning activities ahead of time. - Appoint a common oversight body for co-located projects	2	3	2	0	3	0	3	3	Low
012	C	Risk of: Overall area environmental impacts being increased	Due to: Environmental impacts of developments / operations being combined at co-located sites and worse than separate sites	Resulting in: Increased risk to environment		2	0	3	0	3	0	3	3	Low
013	D	Risk of: Leak from CCUS infrastructure	Due to: Offshore Wind activities	Resulting in: Liability/financial impact on CCUS operator.		2	3	4	3	4	0	4	3	Medium
014	D	Risk of: Leak from CCUS infrastructure	Due to: Failure of CCUS subsea infrastructure / wells / store	Resulting in: Personnel risk to in-field operations, unplanned cessation of in-field operations for Offshore Wind.	- Potential for "high impact" alarms from CCUS to be communicated to co-located Offshore Wind operator. - Study potential impact of well release in more detail.	2	5	5	5	4	0	4	3	Medium
015	D	Risk of: Seabed geophysical changes	Due to: Issues with CCUS storage site	Resulting in: Damage to Offshore Wind Infrastructure and/or change to decommissioning, survey requirements		3	0	0	4	4	4	3	4	Medium
016	D	Risk of: Corrosion of Offshore Wind infrastructure	Due to: Saline aquifer brine release from CCUS operations	Resulting in: Damage to Offshore Wind Infrastructure	- Study work to assess the potential dispersion of brine and establish recommended practice for the distance required between water relief well outlets and offshore wind structures	1	0	0	3	3	0	3	4	Low
017	E	Risk of: Restricted access to drill relief well in the event of CCUS leak	Due to: Access being blocked by Offshore Wind infrastructure	Resulting in: Extended CO2 release from CCUS store		1	3	5	5	5	0	4	5	Medium
018	E	Risk of: Restricted access to CCUS infrastructure	Due to: Access being blocked by Offshore Wind infrastructure	Resulting in: Inability to carry out CCUS operational activities (e.g. well workover, inspection, maintenance, etc.)	- Potential for a common oversight body to mediate between co-located projects	2	0	0	3	2	0	1	3	Low
019	D	Risk of: Damage to Offshore Wind infrastructure	Due to: CCUS activities including drilling of wells, seismic operations, etc.	Resulting in: Liability/financial impact on Offshore Wind operator	- Need to study potential for drilling and seismic interaction to determine whether this is an issue or whether exclusion zones can resolve it	2	0	0	4	3	0	2	4	Medium
020	-	Risk of: Difficulty in gaining insurance cover	Due to: Inability to properly categorise and quantify risks for co-developed areas	Resulting in: Increased insurance premiums	- Mitigation is the outcome of this risk study and any follow on studies into areas of "not easily" mitigated risk that are caused by co-location - Potential for a common oversight body or independent group to show active monitoring of risks and provide good communication to insurance industry	2	0	0	0	2	2	0	3	Low

		Risk Description				Post-Mitigation Assessment								
ID	Common Element	Risk	Cause	Consequence	Future Practice Mitigation	Future Practice Probability	Personnel Impact (P)	Environment Impact (E)	Asset Impact (A)	Reputation Impact (R)	Schedule Impact (H)	Social Impact (S)	Financial Impact (F)	Future Practice Assessment
021	A	Risk of: Lack of clarity over-fishing interaction issues	Due to: Seabed infrastructure during operation or post-decommissioning	Resulting in: Unforeseen costs to CCUS or Offshore Wind operators	- Similar to the other risks really concentrated on the post-decommissioning phase - An aligned set of decommissioning requirements and understanding would be of benefit as would a single regulator across industries - Potential learnings from the oil and gas industry with regards to the "fishermen's fund" would also be beneficial - Possibility to establish a single fund across all offshore industries that aren't fishing	1	0	0	0	2	0	2	2	Very Low
022	A	Risk of: Extended project implementation schedule	Due to: Co-location of Offshore Wind and CCUS projects	Resulting in: Financial/regulatory impact on developing operator	- Potential common oversight body to promote co-ordination for cross-industry developments - Potential independent group that deals with planning opportunities between parties.	3	0	0	0	2	4	3	3	Medium
023	A	Risk of: Poor project execution	Due to: Unclear or conflicting permitting / consent regime for co-located projects	Resulting in: Financial and schedule impact on developing operator	- Compare regulatory / permit regimes across CCUS and Offshore Wind and ensure alignment in common areas – a common oversight body would assist in this	3	0	0	0	2	4	3	3	Medium
024	C	Risk of: Poor management of shared resources	Due to: Unclear "ownership" and prioritisation of shared resources such as emergency response, logistics and infrastructure (such as power)	Resulting in: Increased operational costs to operators		2	0	0	0	2	0	0	2	Low
025	C	Risk of: Overall area noise limits being exceeded	Due to: Cumulative impact of multiple operations	Resulting in: Potential fines to operators and impacts on local environment		1	0	3	0	4	0	0	2	Low
026	E	Risk of: Requirement to modify existing infrastructure	Due to: Access / infrastructure requirements of new CCUS or Offshore Wind development	Resulting in: Financial impact on existing infrastructure operator	- Mitigation would be centred around pro-actively planning for co-location at "high potential" common areas - This should limit the potential for unknown co-location issues on infrastructure requirements	2	0	0	0	2	3	0	3	Low
027	E	Risk of: Need to install or remove more infrastructure than "ideal", including future CCUS expansion	Due to: Presence of existing or planned CCUS or Offshore Wind development	Resulting in: Financial impact on developing operator	- Mitigation would be centred around pro-actively planning for co-location at "high potential" common areas - This should limit the potential for unknown co-location issues on infrastructure requirements	2	0	0	0	2	3	0	3	Low
028	C	Risk of: Poor coordination of activities between developers	Due to: Complex schedules required for CCUS and Offshore Wind developments and operations being difficult to align	Resulting in: Financial and safety impacts on both CCUS and Offshore Wind operators	- Potential for a common oversight body to promote co-ordination for cross-industry developments	3	3	0	1	2	3	0	3	Medium
029	B	Risk of: Restricted access to CCUS storage site for towed streamer seismic surveys	Due to: Current, planned or future potential Offshore Wind infrastructure (note that this could be worse for floating offshore wind)	Resulting in: Most likely to inability to carry out planned towed streamer survey. At best, increased costs for towed streamer survey & difficulty in getting suitably "repeatable" seismic survey results	- Potential to require offshore wind projects to perform 3D seismic over their seabed area during development. - Further develop potential for alternative exploration 3D seismic technologies to towed streamer to provide a cost effective method that is compatible with offshore wind being in place - Assess existing seismic data to determine whether it is suitable for re-processing instead of obtaining new 3D seismic information and highlight areas that are not suitable so that these can be taken into account when planning an offshore wind development - Potential to relax requirements for seismic survey to "prove" store as part of permit application process?	2	0	0	0	2	3	3	3	Low
030	B	Risk of: Poor quality CCUS seismic monitoring	Due to: Noise interaction from Offshore Wind infrastructure / operations and structural movement of turbines	Resulting in: Inability to properly monitor CCUS storage, potential financial penalties on CCUS operator.	- Study potential noise impacts of "normal" offshore wind operation on seismic data quality to determine scale of impact - can't quantify this yet. - Study potential degradation of seismic data by "typical" offshore wind pile structures - can't quantify this yet. - Develop bespoke MMV strategy for overlap sites on a case by case basis with input from CCUS and Offshore Wind developers. - Develop technology to use wind farm "noise" as source for seismic survey. - Find the best quality available survey methods to deploy. - Investigate whether noise characteristics from Offshore Wind are similar to oil and gas operations and determine whether there are lessons to be learned from that sector.	3	0	0	2	4	0	3	5	High
031	B	Risk of: Inability to co-locate Offshore Wind with existing CCUS	Due to: Seismic survey operations prohibiting access to CCUS area for Offshore Wind developments	Resulting in: "Loss" of seabed area for Offshore Wind developments	- Further develop potential for alternative CCUS reservoir monitoring technologies to towed streamer seismic to provide a cost effective method that is compatible with offshore wind being in place - Relate mitigations back to noise interaction with Offshore Wind risk. - Use existing oil and gas or Offshore Wind assets to test MMV methods; no need to wait for CCUS pilot projects. - Ensure data is shared so that learning can be exploited to benefit all sectors. - Establish a joint industry project to develop overlap enabling technology. - Review and quantify the requirements for CCUS MMV to educate and allow more effective strategic planning from both sectors.	2	0	0	0	4	0	3	4	Medium

		Risk Description				Post-Mitigation Assessment								
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032	B	Risk of: Damage to Offshore Wind infrastructure	Due to: seismic monitoring operations	Resulting in: Financial impact on Offshore Wind and CCUS operator	- Same mitigations as blocking access, look at potential alternative monitoring technologies and avoid the issue of damage	1	0	0	2	2	0	2	3	Low
033	B	Risk of: Restricted access to CCUS storage site for "other" storage site surveys	Due to: Current or planned Offshore Wind operations	Resulting in: Inability to carry out planned seismic survey, increased costs for seismic survey, difficulty in getting suitably "repeatable" seismic survey results	- Clearly define "best practice" and "minimum allowable" monitoring and verification schemes for CCUS and their operational requirements - Invest in development of CCUS monitoring and verification technologies that do not cause issues with interaction	2	0	0	0	2	3	2	3	Low
034	-	Risk of: Lack of knowledge retention / lessons learned for SIMOPS	Due to: Long periods between installation and decommissioning activities for CCUS and Offshore Wind	Resulting in: Poor project execution	- Potentially scope to hold a central "lessons learned" database for Offshore Wind and CCUS projects to enable best practice knowledge sharing	2	0	0	3	3	3	2	3	Medium
035	C	Risk of: Poor response to 3rd party emergency in area	Due to: Lack of emergency response coordination between CCUS and Offshore Wind developers	Resulting in: Potential personnel risk for 3rd parties plus financial/liability issues for CCUS and Offshore Wind operators	- Potential for a common oversight body to ensure alignment / sharing of emergency response	2	4	0	0	4	0	4	3	Medium
036	C	Risk of: Safety impact on divers during operations	Due to: Uncoordinated operations between CCUS and Offshore Wind developers	Resulting in: Potential major injury or loss of life for divers, schedule delays	- Potential for a common oversight body (for safety in this case) to promote collaboration and co-ordination across co-located projects.	2	4	0	0	4	2	4	4	Medium
037	D	Risk of: Damage to CCUS infrastructure	Due to: Offshore Wind activities	Resulting in: Financial impact on CCUS operator, potential leak from infrastructure (reference risk 013)		2	3	3	4	4	0	4	2	Medium
038	A	Risk of: Decommissioning programme "incomplete"	Due to: Co-location of Offshore Wind and CCUS infrastructure	Resulting in: Lack of clarity over who "owns" decommissioned infrastructure left in-situ	- Common set of standards for decommissioning and expectation of what could potentially be left on seabed - Take lessons learned currently being experienced in offshore oil and gas industry for this subject and how OSPAR is being interpreted - Appointment of a single regulator across all industries would be beneficial in this area	1	0	2	0	3	3	2	3	Low
039	A	Risk of: Unforeseen project installation delays	Due to: Vendor delivery periods changing in co-located project	Resulting in: Financial / liability impact across projects (who pays for delays?)	- Potential for a common oversight body to "mediate" between co-located projects for liabilities?	3	0	0	0	4	4	3	3	Medium
040	A	Risk of: Cross asset schedule delays	Due to: Less certainty over life expectancy of CCUS	Resulting in: Financial / liability impact across projects (who pays for delays?)	- Potential for a common oversight body to "mediate" between co-located projects for liabilities?	3	0	0	0	4	4	3	3	Medium
041	E	Risk of: Inability to co-locate CCUS with Offshore Wind	Due to: Offshore Wind significantly extending operational lease	Resulting in: "Loss" of potential CCUS storage volumes	- Potential for common oversight body to provide a view over whether new CCUS development or extension of Offshore Wind is of more overall benefit to the UK on a case by case basis - Develop an industry standard to review against.	2	0	0	0	4	0	3	5	Medium
042	C	Risk of: Temporary interruption to CCUS activities	Due to: Asset / safety risk associated with Offshore Wind construction or decommissioning activities	Resulting in: Financial impact on CCUS operator, potential venting of CO2 to atmosphere, etc.		3	0	0	3	3	0	2	3	Medium
043	A	Risk of: Future legislation impacts on co-located projects	Due to: Changes in regulator decommissioning requirements for CCUS and Offshore Wind	Resulting in: Inability to proceed with new CCUS / Offshore Wind projects	- Common set of standards for decommissioning and expectation of what could potentially be left on seabed - Take lessons learned currently being experienced in offshore oil and gas industry for this subject and how OSPAR is being interpreted - Appointment of a common oversight body for co-located projects would be beneficial in this area	1	0	0	0	3	3	2	3	Low
044	A	Risk of: Competition for subsidies	Due to: Funding requirements from CCUS and Offshore Wind potentially coming from same "pot"	Resulting in: Inability to proceed with new CCUS / Offshore Wind projects		3	0	0	0	3	0	3	4	Medium
045	A	Risk of: Damage to environment from infrastructure left on seabed following decommissioning	Due to: Lack of clarity over regulatory regime for CCUS and Offshore Wind	Resulting in: Sustained environmental impact	- Common set of standards for decommissioning and expectation of what could potentially be left on seabed - Take lessons learned currently being experienced in offshore oil and gas industry for this subject and how OSPAR is being interpreted - Appointment of a common oversight body for co-located projects would be beneficial in this area	1	0	3	0	3	0	3	3	Low
046	D	Risk of: Hydrocarbons breach aquifer/ surface	Due to: Reservoir methane propelled by over-pressurised CO2	Resulting in: Cratering, gas escape. Undermines windfarm integrity/ risk of explosion		2	1	5	1	5	0	3	4	Medium

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